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THE EFFECTS OF SOIL MOISTURE, FIELD-SCALE TOPOSEQUENTIAL POSITION, AND SLOPE ON YIELDS IN IRRIGATED UPLAND RICE FIELDS IN FLORES, COMAYAGUA, HONDURAS

By

Kyle M. Earnshaw

A THESIS

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

(Forestry)

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2011

This thesis, “The Effects of Soil Moisture, Field-Scale Toposequential Position, and Slope on Yields in Irrigated Upland Rice Fields in Flores, Comayagua, Honduras,” is hereby approved in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE IN FORESTRY.

School of Forest Resources and Environmental Science

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Date ____________________________________

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Fernando, and the rest from APUFRAM; and Néstor Mendoza and Martín Pérez from the rice association.

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ABSTRACT

Rice (*Oryza sativa* L.) is an important cash crop in Honduras because of the rice lobby's size, willingness to protest, and ability to negotiate favorable price guarantees on a year-to-year basis. Despite the availability of inexpensive irrigation in the study area in Flores, La Villa de San Antonio, Comayagua, the rice farmers do not cultivate the crop using prescribed methods such as land leveling, puddling, and water conservation structures. Soil moisture (Volumetric Water Content) was measured using a soil moisture probe after the termination of the first irrigation within the tillering/vegetative, panicle emergence/flowering, post-flowering/pre-maturation and maturation stages. Yield data was obtained by harvesting on 1 m^2 plots in each soil moisture testing site. Data was analyzed to find the influence of toposequential position along transects, slope, soil moisture, and farmers on yields. The results showed that toposequential position was more important than slope and soil moisture on yields. Soil moisture was not a significant predictor of rice yields. Irrigation politics, precipitation, and land tenure were proposed as the major explanatory variables for this result.

CHAPTER ONE - INTRODUCTION

I joined the Peace Corps, in large part, because I wanted to learn the Russian language. When I received the news that I would be travelling to Honduras, where I would have to learn Spanish, a language I had long avoided because of its prevalence in American life and prominence in my family's history, I was disappointed. I accepted the post, however, and was pleasantly surprised by my work post, co-workers, friends, and the complexity and beauty of Honduras.

After three months of language and cultural training in Zarabanda and San Antonio de la Cuesta during which I lived with two different host families, I was placed with an Irrigation District office in Flores, La Villa de San Antonio in the Department of Comayagua to work with the irrigation district and AGENDA FORESTAL, a non-governmental organization (NGO). The district managed the distribution of irrigation water provided through the El Coyolar Dam, managed by the Department of Natural Resources (SERNA). My work was to center on a payments for environmental services (PES) project was designed to maintain the quality and quantity of water produced in the El Coyolar watershed. Throughout my time in Flores, I consulted on the project and helped solicit a grant from the FAO in order to train the communities in the lower and upper watersheds to work together and calculate the value of the good and services provided by the upper to the lower watershed beneficiaries.

I also worked with APUFRAM, an NGO tasked with the education of girls and boys outside the sphere of the public education system, to develop an ecological park, EcoPark APUFRAM, on 30 hectares of abandoned and degraded cattle pasture owned by the organization. This work included analysis of the land and its flora and fauna, the development of partnerships with local and international universities, NGOs and the Honduran government, the production of more than 4500 seedlings in 22 species for reforestation and reintroduction of important low density and lost species in the park, the design of educational and recreational kiosks, trails, and lookouts, and the design and maintenance of a website for the park.

Finally, I was able to undertake and complete the data collection for my Master's thesis for Michigan Technological University during the rainy season of 2010. During my first six months in site, I thought a lot about rice production in the Irrigation District of Flores. I had not imagined that I would be working with rice during the Peace Corps, but when I arrived in Flores, I was excited to find out that I would have the opportunity to learn about it. Through a literature review and conversations with Parker Filer, another Master's International student and Peace Corps Volunteer in Honduras, I came to suspect that rice farmers in Flores were not optimizing production and water use because of poor land preparation and the absence of water conservation structures.

The purpose of my study is to investigate soil moisture gradients along transects, also called toposequences, in five fields of varying slopes and the subsequent change in rice yields as one moves along the toposequence.

Chapter Two gives a general background of Honduras with information on the history, climate and topography, people, culture, religion, health and economy.

Chapter Three looks more closely at the study area's demographics, climate, and soils. It also provides an in-depth description of rice and rice production.

Chapter Four describes the methods of the study. It addresses field selection, field characterization, soil moisture measurements, soil moisture meter calibration, yield data collection, the farmer interviews, and the tests used in the data analysis.

Chapter Five provides the raw data collected in the study.

Chapter Six provides the results of the data analyses and discussions on erosion, farmers and yields, management styles, land tenure and the value of field studies. The chapter also provides a literature review within the discussion sections as context for the results of this study.

Chapter Seven suggests conclusions that can be drawn from this study. It also proposes subjects and problems for the future study of rice farming in Honduras.

CHAPTER TWO – GENERAL BACKGROUND

Honduras covers 112,090 km^2, an area roughly the size of Tennessee (CIA 2011). It has land borders of 256 km with Guatemala to the northwest, 342 km with El Salvador to the west and 922 km with Nicaragua to the south. Additionally, to the north it has 669 km of coastline on the Caribbean Sea and to the south it has 163 km along the Gulf of Fonseca (Figure 2.1).

Figure 2.1. Map of Central America with Honduras in the center (University of Texas 2011)

The country is a democratic constitutional republic made up of eighteen administrative departments: Yoro, Valle, Santa Barbara, Olancho, Ocotepeque, Lempira, La Paz, Intibucá, Gracias a Dios, Islas de Bahia, Francisco Morazán, El Paraíso, Cortés, Copán, Colón, Choluteca, Atlantida, and Comayagua (U.S. Department of State 2010) (Figure 2.2). Each department contains municipalities with the number depending on the size of the department, population density, and traditional boundaries dating back to Spanish colonial times. The capital is Tegucigalpa.

The current population is 8,143,564 people (CIA 2011). The capital, Tegucigalpa, has a population of 990,600. Other important population centers include San Pedro Sula (646,300), Choloma (223,900), La Ceiba (172,900) and Comayagua (78,300) (Brinkhoff 2009). Fifty-two percent of the population lives in an urban setting (CIA 2011).

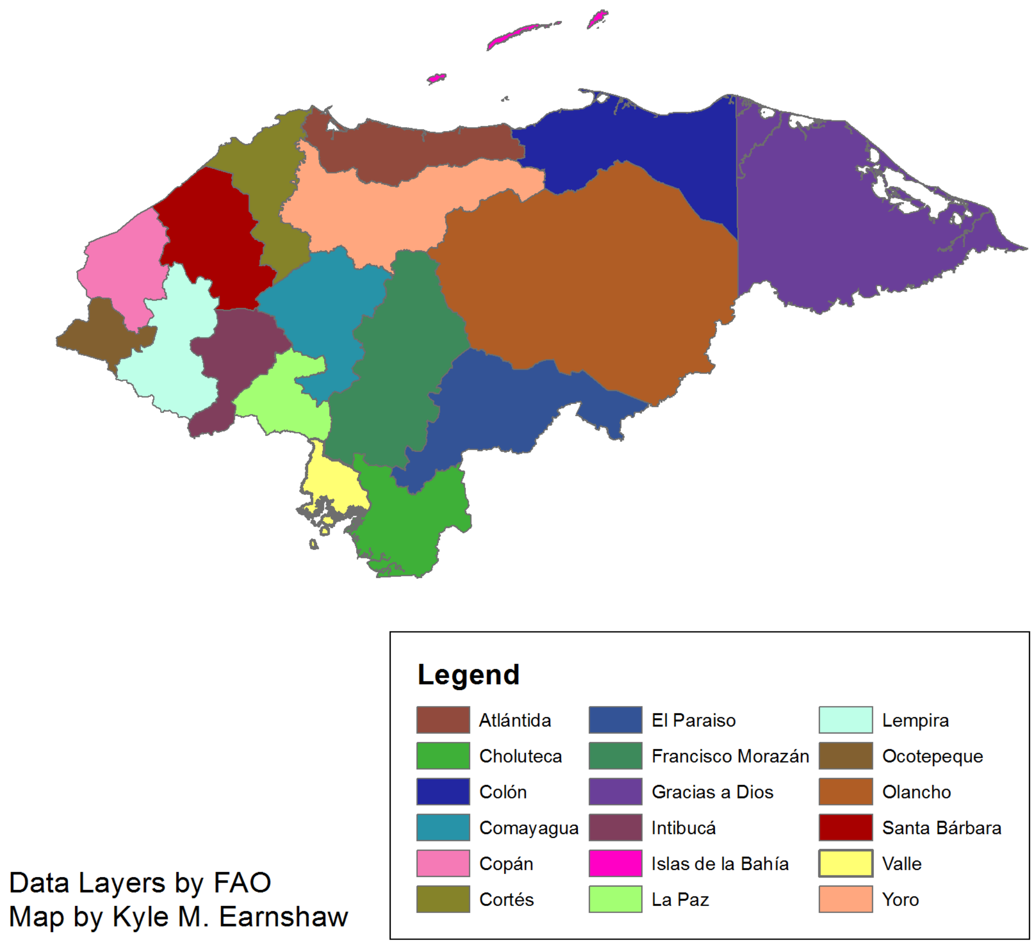

Figure 2.2. The administrative departments of Honduras.

2.1 History

In 1502, Columbus arrived at the north coast of Honduras on his fourth voyage to the New World (Leonard 2011). The Spanish then established their power with their first colony in Honduras in 1524. After the Spanish quashed the rebellion of Chief Lenca in 1537, they ruled the region through the colonial power center, Guatemala, until September 15th of 1821 when Spain lost its hold on Central America and Honduras was annexed by the Mexican Empire before joining the United Provinces of Central America federation in 1823 (U.S. Department of State 2010; Leonard 2011). In 1838, the federation broke apart, despite the efforts of the national hero, General Francisco Morazán, and Honduras became fully independent (U.S. Department of State 2010).

2.2 Climate and Topography

With borders on both the Caribbean and Pacific oceans (Gulf of Fonseca) and elevations varying from sea level to more than 8000 feet near Gracias, Lempira, Honduras contains many ecosystems (Bengtson 1926; U.S. State Department 2010). These zones include various types of cloud, rain, and dry forests (Figure 2.3).

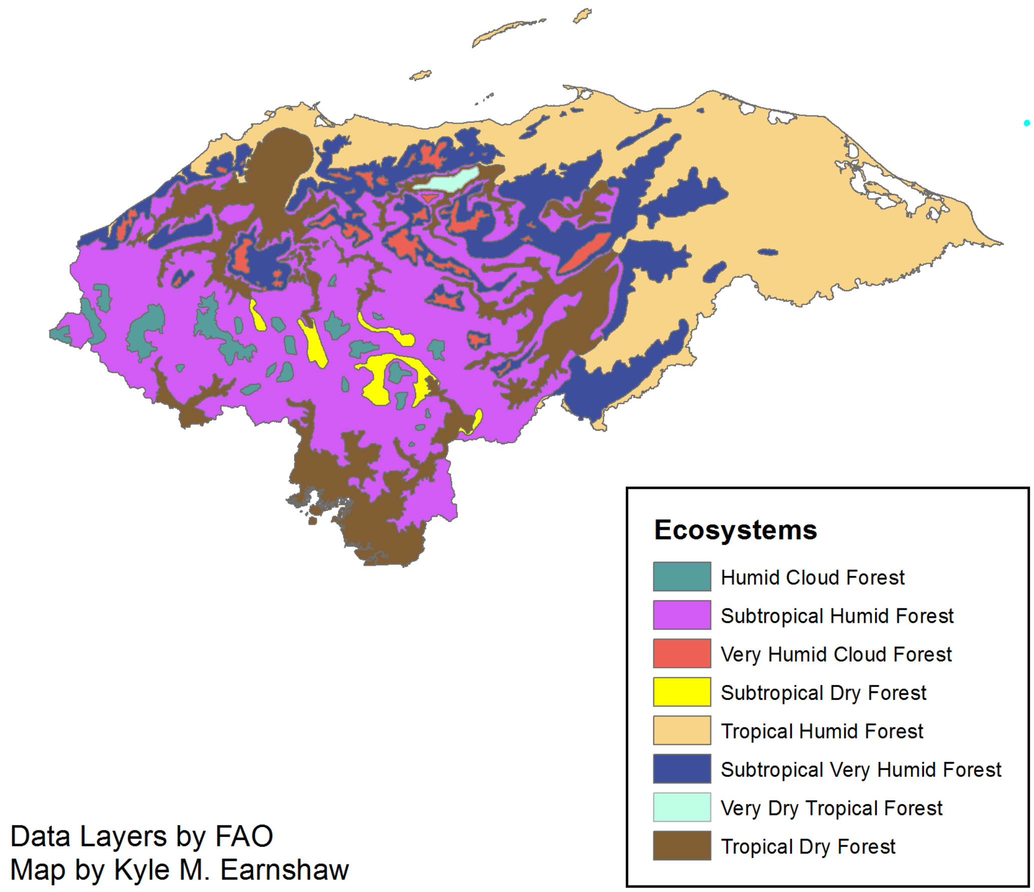

Figure 2.3. The ecosystems of Honduras are largely determined by position, both vertically and spatially, as related to mountains.

Precipitation ranges from less than 550 to more than 3300 mm per year (Figure 2.4). In addition to coastal influences on precipitation, mountains also play a major role because of cloud forests. Cloud forests are areas high up on mountains where the presence of frequent ground cloud cover causes increased condensation through increased humidity (Grubb 1977; Stadmüller 1987). Honduras has 24,709 km^2 of cloud forest, accounting for 18.3% of the total land area (Mulligan and Burke 2005). In 1987, Honduras ruled all land above 1800 meters above sea level protected cloud forest. This was because of the importance of cloud forests for water production (Government of Honduras 1987). These areas, such as La Tigra National Park to the north of the capital, provide significant percentages of the water supply for many Honduran cities (Hamilton 2008).

Unfortunately for Honduras, its position puts it in a dangerous location for hurricanes. The most notable example of this was Hurricane Mitch in 1998, which cost Honduras almost $3 billion dollars, more than 5,000 lives, left more than 1.5 million people without homes and undid years of development (CIA 2011). Honduras also experiences many earthquakes, the majority of which are insignificant.

Average temperatures range from less than 6º C on the mountaintops to more than 28º C in the hot southern lowlands around the Gulf of Fonseca (Figure 2.5).

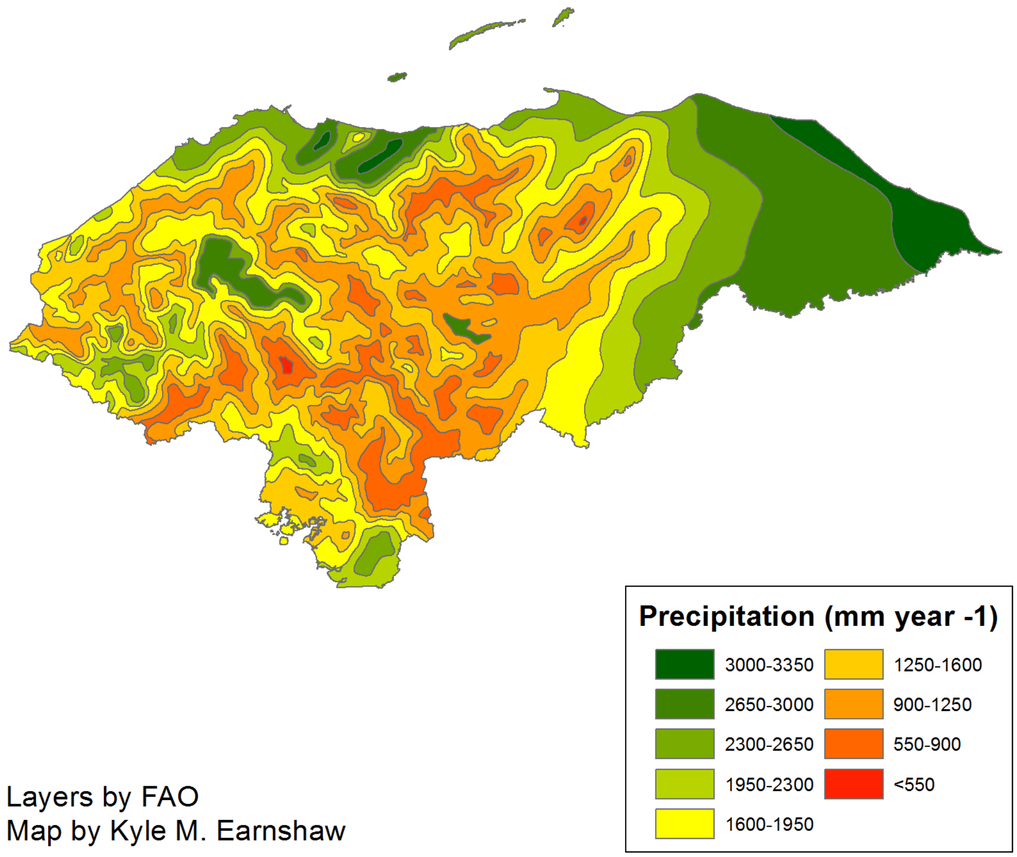

Figure 2.4. Annual precipitation (mm) in Honduras

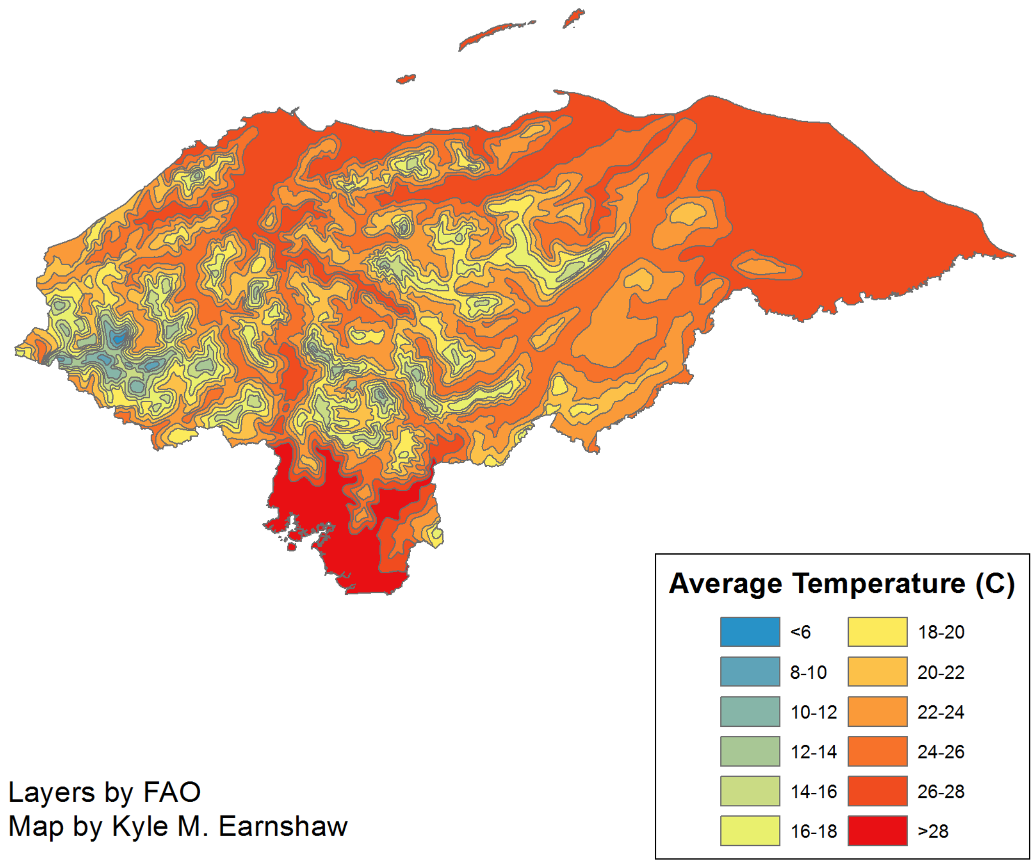

Figure 2.5. Average temperature (C) in Honduras

2.3 The People, Culture, and Religion

By Central American standards, Honduras does not have the rich cultural heritage that countries like Mexico and Guatemala have. Ninety-percent of the population is considered *mestizo*, of mixed race (CIA 2011). Honduras does have, nonetheless, eight other recognized ethnic groups: the Tolupán, Pech, Misquito, Lenca (the largest), Tawakha, Chortí, Garífuna and *Negro Inglés* (Anderson 2007). The first six of these make up the 7% of the population called Amerindian. The last two make up the part of the population designated "black." The rest of the population (1%) is white (CIA 2011).

Each group adds its own spice to the Honduran culture (Figure 2.6). The Lenca, for example, provided Honduras with its first national hero, Lempira, the leader of the initial rebellion against the Spanish. They are also known for their pottery, a favorite among tourists. The Garífuna, also an artistic group, are known for their style of dance, the *punta*. In spite of their contributions to society, however, all of these groups have experienced significant persecution before and after Honduras' independence (Cabezas 2008).

Figure 2.6. Kyle's host father dances a traditional dance during Children's Day on September 10th. Photo by Kyle M. Earnshaw.

This richness of culture makes the current state of affairs all the more saddening. Over the past few years, crime in Honduras has gone steadily upwards. In the early 2000s, the gangs, or *maras*, were already a large enough problem so that President Maduro ran his campaign on a ticket of zero tolerance towards them. Under him, it was made illegal to be a member of a *mara* and one would go to prison for 12 years if caught. Although the public supported his tactics, by which the country saw an 80% decline in kidnapping and a 60% decline in youth violence, the world's human rights groups opposed the tactics. President Zelaya, who followed Maduro, tried other tactics but soon fell back on harsher measures (Sullivan 2006).

Now there is evidence that these efforts could be for naught. As Mexico becomes stronger, the *mafias* are moving southward into Guatemala, El Salvador and Honduras, the so-called "northern triangle" or "triangle of fire" (Economist 2011b). Honduras already has the highest murder rate in the world, followed by El Salvador (Economist 2011a). Murder rates and crimes by minors are increasing. The *mafias* are taking advantage of the government's weak infrastructure and the already established *mara* system in order to expand their influence and move narco-trafficking operations to more hospitable territory (Economist 2011b). The National Commission for Human Rights in Honduras (CONADEH) estimates that the final homicide rate for Honduras in 2011 will be 86 per 100,000, up from 66.8 in 2009 and 57.9 in 2008 (IUDPAS-UNAH 2009; IUDPAS-UNAH 2010; El Heraldo 2011). When speaking of young males between the ages of 20-24, the rate was as high as 253.4 per 100,000 in 2009 (IUDPAS-UNAH 2010). As a point of comparison, the murder rate per 100,000 in the U.S.A. in 2009 was five (Disaster Center 2010). While not a perfect comparison and itself a troubling statistic, the murder rate in 2005 by firearm in the United States was 9.3 per 100,000 for whites and 101.9 for blacks (Hu et. al 2008). Clearly, violent crime is a serious problem for Honduras and significantly hinders the attempts of its youth to build good lives.

Honduras is predominately Roman Catholic at a percentage of 97%. The remaining 3% is Protestant, although small minorities of Muslims and Jews are found in Honduras, evidenced by small groups of Muslims going on pilgrimages to Saudi Arabia and the presence of one Jewish temple in Tegucigalpa (Luxner 2001; CIA 2011; Rosen 2011).

2.4 Health

In the cities, 95% of the population has access to drinking water brought close to the house, plot or yard. Eighty-percent of them have access to improved sanitary facilities. In rural areas, only 77% of the population has access to improved drinking water and 62% to improved sanitary facilities (CIA 2011). The results of a socio-diagnostic survey that I completed in the 17 house hamlet of Los Valles, La Villa San Antonio, Comayagua showed only 46.67% had water inside the house, 66.67% had dirt floors, 88% cooked on unimproved stoves, 20% used an unimproved pit-latrine, 70% used an improved washable latrine, and only 13.33% had access to electricity. In my experience, this was a typical small rural community.

2.5 Economy

Honduras, where nearly 60% of the population lives below the poverty line, has the unfortunate distinction as the second-poorest country in Central America (World Bank 2011). For many years, its economy has been dependent on trade with the United States. Important goods include coffee, bananas, textiles, shrimp and lobster, fruits and livestock (U.S. State Department 2010; CIA 2011). It has an unemployment rate of 5.1%. Those that have jobs work in agriculture (39.2%), industry (20.9%) and services (39.8%) (CIA 2011). Honduras is a member of CAFTA, which has opened up the country for foreign investment, especially in the *maquila* (textile) sector, but also brought difficulty to farmers through lowered protection (Morley and Piñeiro 2006). The country under President Lobo is currently trying to rebound from difficult years during the Zelaya presidency and the *coup d'état* that followed (CIA 2011).

CHAPTER THREE – STUDY AREA BACKGROUND

The study took place in Flores and Puente San José in La Villa de San Antonio, Comayagua (Figure 3.1). They are both located between 15-20 km from Comayagua, the department capital. Flores, the second most important town in the municipality of La Villa, is a community of roughly 1100 houses and 5000 people. Puente San José has about 200 inhabitants. After the construction of the El Coyolar Dam in 1956-57 and its expansion and restoration in 1995-96, funded by Kuwait, Flores has developed improved water and sanitary access. It has two water systems: one goes into the houses and is untreated and another that provides filtered water to a system of faucets throughout the town. The sanitary system provides almost every house with sanitary facilities, but it does not have a means of treating the waste, which ends up in the Río San José outside of town.

Flores has access to many modern amenities. It has two internet cafés, cable television access, electricity, a health center, a kindergarten, two elementary schools, two high schools, two pharmacies, two hardware stores, and many corner stores where food and other commonly needed household items can be found. It is also the main center for APUFRAM, an NGO with educational facilities throughout the country focusing on providing education to children from areas outside the scope of the public school system.

Aside from an elementary school, electricity and a corner store, Puente San José does not have access to the same amenities except through Flores about five kilometers away. Especially Flores, but also Puente San José, is located in a prime location for transportation. The Pan-American Highway, CA-5, runs through the middle of Flores and provides its inhabitants with buses all day and every day to Tegucigalpa, Comayagua, La Paz,

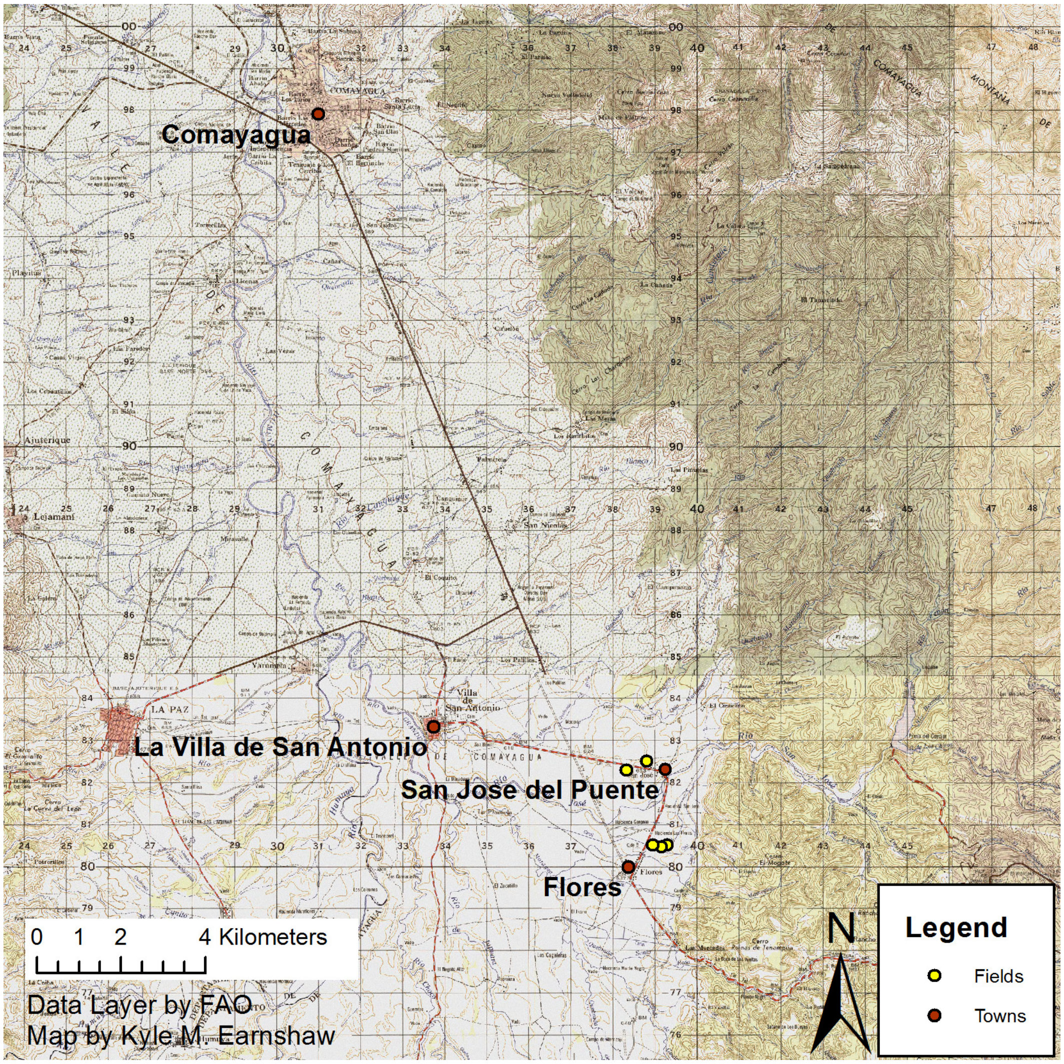

Figure 3.1. The five fields used in this study are shown in relation to nearby towns and cities. Note that the map is not up-to-date. The main highway (CA-5) no longer makes an "S" shape, but rather goes directly from Flores to Comayagua.

Siguatepeque, San Pedro Sula, La Esperanza, La Ceiba, Trujillo and any town along those routes.

The people of Flores are generally better off than people living in the mountains or outside the irrigation district. The residents range for the most part from poor middle class to upper middle class and even upper class. For example, a vice-mayor of the capital, Tegucigalpa, lives less than a kilometer from the town. The houses are generally made of adobe or concrete blocks, have concrete or ceramic tile floors and contain three to seven or more rooms. The roofs can be either clay tiles or aluminum or zinc lamina. Many houses are simple rectangles but some are two- or more storied or have a central courtyard. Residents frequently make money by building extra rooms or apartment buildings to be rented out to short-term residents, often temporary workers attracted by irrigated dry season agriculture. This has raised the price of residential and agricultural land in the area.

Many people, nonetheless, are much poorer than the normal *Floreño* and live on the outskirts of town in poorly-constructed mud homes with no access to electricity or running water. A majority of the poorest families construct their homes along the primary canal system and use its water for bathing, cooking and washing. These homes are often extra-legal.

3.1 Climate and Soils

The area of Flores in the Valley of Comayagua has an altitude of about 620 meters above sea level. Mt. Comayagua (2,405 meters) to the north and east, Mt. Yerba Buena (2,243 meters) to the south, and the Cordillera of Montecillos (2400+ meters) to the west surround the region. Mt. Comayagua especially affects the weather of the Valley because of the rain shadow it creates to the south and west of it.

Between 1972 and 1986, Flores received an average annual precipitation of 876 mm with a highly variable decadal and bimodal distribution (Almedarez 1988) (Tables 3.1 and 3.2; Figure 3.2). The data shows that, in a normal year, Flores has a 25% chance of receiving at least 1127 mm, a 50% chance of receiving at least 820 mm and a 75% chance of receiving at least 574 mm rainfall. Even during the rainy season, however, based on the data from 1972-1986 alone, Flores would not be an important agricultural area without irrigation because of frequent week or two week long droughts during the rainy season (see Appendix A for more details). A weather station connected to IAGSA, an agricultural firm, in Las Mercedes, about 3 and 5 km away from the sites, recorded precipitation data for 2008, 2009 and 2010. In those years, precipitation measured 820, 1073 and 1479 mm respectively (IAGSA 2011). In 2009, the station recorded 888 mm of precipitation between May and September before recording 93 mm and 41 mm of precipitation for October and November, respectively. In 2010, the station recorded 1226 mm

Table 3.1.

Decadal precipitation in mm in Flores, La Villa de San Antonio, Comayagua, Honduras between 1972 and 1986. From Almedarez (1988).

Decade	J	F	M	A	M	J	J	A	S	O	N	D
1	1.0	1.0	1.2	4.8	18.1	71.0	32.2	27.5	61.0	36.4	12.6	4.9
2	0.6	4.9	3.7	15.0	15.0	72.2	22.6	33.7	113.0	26.2	7.7	2.0
3	0.9	0.3	3.9	21.6	60.0	40.0	40.6	59.6	65.5	31.8	5.9	1.4

Table 3.2.

Monthly precipitation in mm in Flores, La Villa de San Antonio, Comayagua, Honduras between 1972 and 1986. From Almedarez (1988).

J	F	M	A	M	J	J	A	S	O	N	D
2.7	6.5	8.4	42.3	124.5	185.4	92.7	120.6	161.2	95.6	26.8	8.4

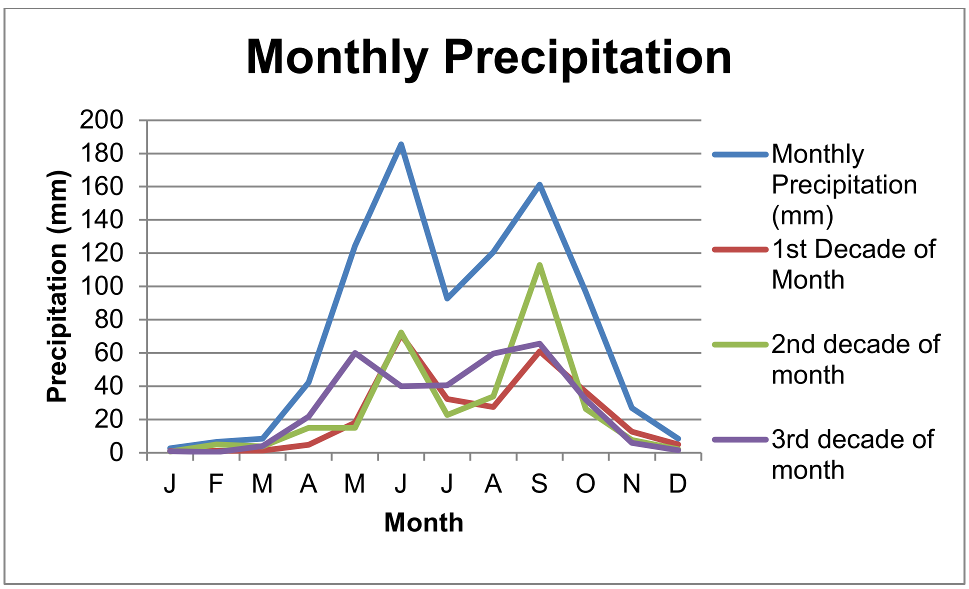

Figure 3.2. Monthly and decadal precipitation in Flores, La Villa de San Antonio, Comayagua. Developed from Almedarez 1988.

(245 mm $month^{-1}$) of precipitation between May and September before readings of 19 mm for October and 64 mm for November.

Temperature in Flores averages 24.3ºC (Almedarez 1988). The average minimum and maximum temperatures for the year are 16ºC in January (8.2ºC absolute minimum) and 32.5ºC in April (35.7º C absolute maximum in March). The soil temperature during the course of the year averages 25.9ºC at 5 and 30 centimeters depth and 26.3ºC at 50 cm. The average monthly relative humidity is 70% and the average monthly evaporation rate is 163 mm (high of 239 mm of evaporation in March and low of 123 mm in November). The average monthly solar radiation is 334 cal $cm^{2\ -1}$ day^{-1} with a high of 464 cal $cm^{2\ -1}$ day^{-1} in March and a low of 288 cal $cm^{2\ -1}$ day^{-1} in January. Average wind speeds measure at 4.2 km $hour^{-1}$ with average monthly highs of 6.3 km $hour^{-1}$ in February and monthly lows 2.4 km $hour^{-1}$ in September.

The soils around Flores are classified as "Valley Soils" and gleysols (Almedarez 1988). Valley soils are alluvial and well or moderately drained with depths of between 70 and 150 cm. These soils were deposited as runoff and erosion from the surrounding mountains. The gleying is a result of periodic flooding or a variably high water table that reduces the oxygen in the soil and causes a chemical change in the iron to its mobile ferrous form (Fanning and Fanning 1989; Buol et. al 2003). This then causes a leaching in iron from one horizon in the soil to another below causing a line of low chroma or gray above a horizon of rust colored soil below (Fanning and Fanning 1989). The valley soils can have textures from sandy loams to clay loams and pure clays. Natural unmanaged soils typically have neutral pHs but can vary from 6.5 to 7.8 pH. Valley soils typically also have high levels of potassium, low to medium cation exchange capacity, high base saturation and low levels of phosphorous (Almedarez 1988).

3.2 Agriculture

The Irrigation District of Flores was established with the building of the El Coyolar Dam and allows most people to farm throughout the year. It also allows for diversification of crops and a focus on cash crops. During the wet season, from roughly May until the end of September, a majority of the land under irrigation is used for cultivation of rice (Figure 3.3). Corn, king grass, sorghum and mangos are examples of the other important crops grown during the wet season. During the dry season, corn, sorghum and king grass are still important crops while beans, pasture and plantains join them as the largest uses of irrigation water (Figure 3.4). Rice is not grown during the long dry season from October until April because the irrigation authorities do not believe they can guarantee enough water for rice during that season. Pasture, king grass and an assortment of other grasses become important during the dry season as cattle farmers try to keep their cattle fed.

The Irrigation District of Flores charges 100 lempiras (about $5.25) for 1200 m^3 of water for gravity irrigation on one *manzana* (0.70 ha). In order to irrigate a field, the farmer goes to the irrigation office and pays for the number of *manzanas* the farmer wants irrigated. The farmer then tells a *canalero*, the man in charge of opening and closing the locked canal doors for the farmers, when the farmer wants the field irrigated. The *canalero* then is supposed to open up the canal door and allow for approximately 1200 m^3 of water to enter the field for every *manzana*. Many factors, including the impossibility of truly measuring water volume, the danger involved in enforcing the law and the temptation of taking bribes, usually means that much more than 1200 m^3 of water enters the farm field. The Irrigation District also allows farmers to fill up lagoons in order to use drip irrigation and thereby conserve water. The current price for this is still the same as for

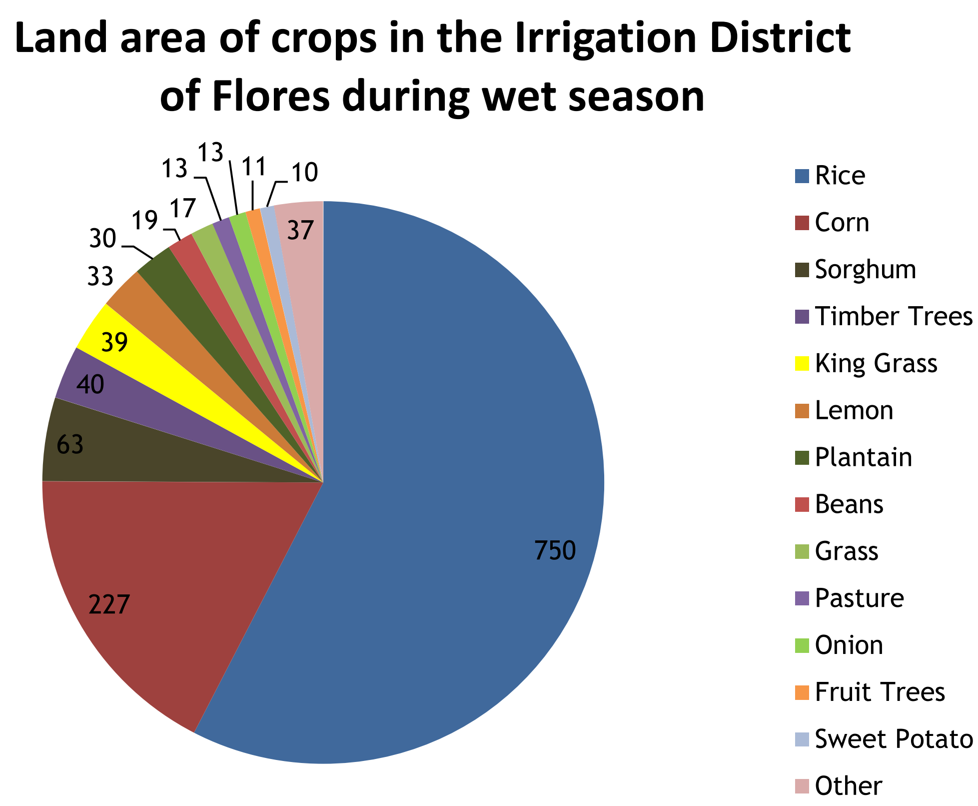

Figure 3.3. Rainy season crop distribution during the rainy season in the Irrigation District of Flores in La Villa de San Antonio, Comayagua, Honduras in 2010. All numbers are in hectares.

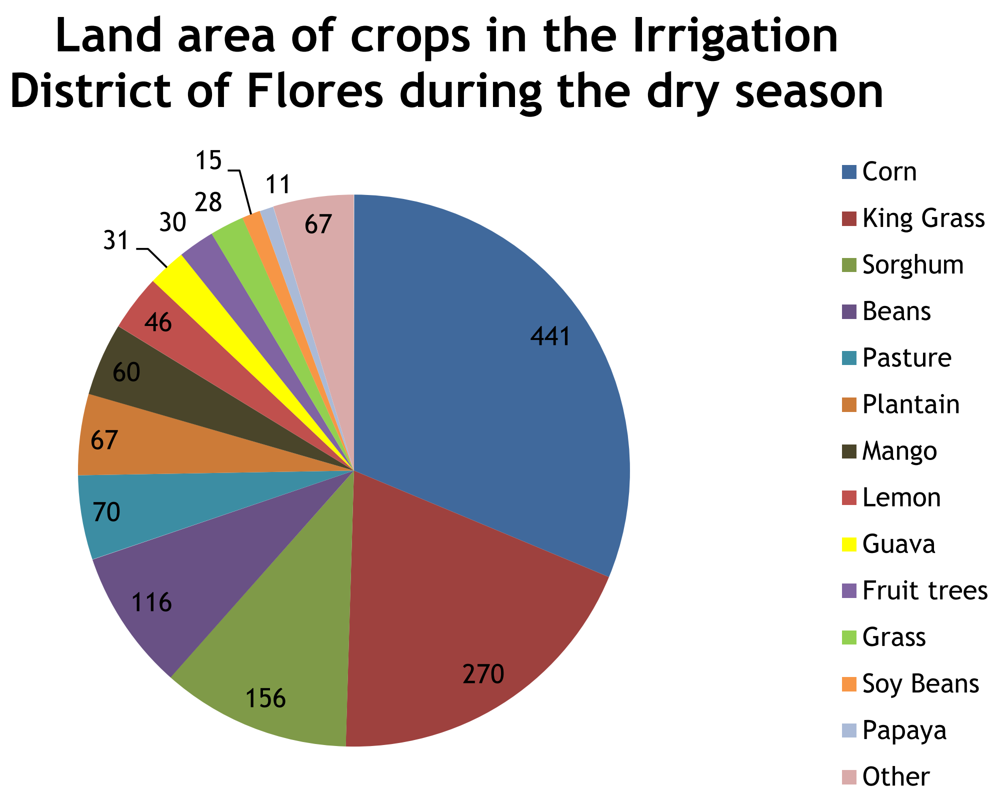

Figure 3.4. Dry season crop distribution during the rainy season in the Irrigation District of Flores in La Villa de San Antonio, Comayagua, Honduras in 2010. All numbers are in hectares.

gravity irrigation, but the Irrigation Office is considering charging more for this because farmers can usually get three irrigations out of a lagoon and do not buy water as frequently.

3.3. Rice

Although it has not always been the case, Rice, *Oryza sativa* L., is currently an important cash crop in Honduras because of the high and guaranteed price for which that the rice farmers negotiate with the government on a yearly basis. The guarantee, however, is not something that has been easily achieved or maintained. Based on my observations and conversations with rice farmers, the rice farmers, in order to receive the negotiated price, often have to take to the highways to protest when the government claims that the price was never negotiated. During the year of this study, the rice farmers took control of CA-5 multiple times in protest. Although peaceful, many farmers were sent to jail and a few were even beaten as a result of their presence on the streets. The protests, nonetheless, were successful and showed why rice has been a profitable cash crop in Honduras.

Rice is cultivated throughout the world from latitudes 53N to 35S and from sea level up to 2500 meters above sea level (De Datta 1981; Yoshida 1981). Rice can be grown on all soil textures. The pH can range from 3-10, the organic matter content from 1-50% and salt content in the soil from 0-1% (De Datta 1981).

The method of cultivation changes based mainly upon water availability. The main systems of rice production are upland, rainfed lowland, irrigated lowland, deepwater and floating. Systems that combine or alter those mentioned exist. For example, some upland rainfed systems rely on irrigation for supplementary water inputs. Average yearly precipitation commonly ranges from 1200-2000 mm year^{-1} even though some studies have shown that water stress can occur even in areas with annual precipitation over 2000 mm (Jana and De Datta 1971). For yields coinciding with rice's normal potential in a variety of rice systems, precipitations of 200 mm month^{-1} and 50 mm 10days^{-1} have been proposed as minimum levels necessary to meet rice's water needs (De Datta 1981; Steinmetz et. al 1984). Twenty-nine out of the year's thirty-six 10-day decades in Flores from 1972-1986 received on average fewer than 50mm of rain, meaning that only two months during the year provide enough precipitation for upland rice production (Table 3.1; Figure 3.2). This is shorter than the shortest cropping season for rice: three months. The two months of rain, moreover, are not successive. This means that Flores would not be suitable for upland rice production without irrigation. Some researchers have found, however, that upland rice systems and irrigated lowland systems in Southeast Asia only require about 95 mm and 175 mm of rain mo^{-1}, respectively, for acceptable levels of production (Gupta and O'Toole 1986). The suitability of regions with lower rainfall levels depends largely on precipitation's distribution throughout the year.

Temperatures for rice production on average fall between 25-31ºC, but certain stages such as the establishment and rooting stages prefer temperatures between 25-28 ºC while the anthesis stage is best between 30-33 ºC (Yoshida 1978; De Datta 1981). Rice can grow in conditions with temperatures as high as 35-38º C, but that can cause sterility in sensitive varieties (Satake and Yoshida 1978; De Datta 1981). Sterility can also be a problem when the temperature drops below 18-20º C during the reproductive stages, a common problem in many upland rice systems (Nishiyama 1969 as cited in De Datta 1981; Gupta and O'Toole 1986).

Under conditions where water is not limiting, rice prefers solar radiation on the high end of 300-500 cal $cm^{2 -1}$ day^{-1} in the tropics during the ripening period (De Datta 1981). The panicle initiation stage, however, is the most important time for rice to receive high levels of solar radiation in order to maximize yields (Stansel et. al 1965; Stansel 1975). In contrast to irrigated lowland rice, which prefers high levels of solar radiation, it is possible that upland rice reacts differently and may experience yield losses with increased solar radiation as a result of water stress (Gupta and O'Toole 1986). In more arid regions, soil moisture is more important than solar radiation (Das Gupta 1983 from Gupta and O'Toole 1986).

The main growth stages are the vegetative, reproductive and ripening stages. The vegetative stage begins after germination with emergence and proceeds through the seedling, tillering, maximum tillering and stem elongation phases. The reproductive stage begins with panicle initiation and continues through booting, heading, flowering, pollinization and fertilization. It is possible in short-duration varieties of rice, those that mature in 105 days after the planting date, for the stem elongation and panicle initiation phases to occur simultaneously. Long-duration varieties, those that mature 135-160 days after seeding, do not combine these phases. Finally, the ripening stage includes the milk, dough and mature phases (De Datta 1981; Yoshida 1981).

The variety of rice grown by farmers in this study, DICTA 6-60, was developed by the Department of Farming and Livestock Science and Technology (DICTA). Studies conducted by them in various regions of Honduras have produced data on the growth and physiological characteristics of the variety. DICTA 6-60 is a long-duration rice variety that grows to an average height of 70.4 cm (range of 52-84 cm) (FHIA 2006). Rice's root systems commonly grow to a depth of 50 cm (FAO 1986). The panicle of about 22.2 cm contains on average 142 sprinklets (FHIA 2006). It takes 90 days to reach the flowering stage when, like in most varieties, the flowers open from around 9 a.m. until 3 p.m. and the plants are self-pollinated (De Datta 1981; FHIA 2006). The fruits produced are on average 8.7 mm long (FHIA 2006). Disease reduces yields 1-5%. DICTA 6-60 averages yields of 4.74 t ha^{-1} at 13% grain humidity (range from 3.18-8.5 t ha^{-1}). On average, 20% of the grains are broken. One-thousand grains weigh 28.8 grams.

The yields of DICTA 6-60 are normal for many rice varieties in the rainy season. Yields during the dry season are often much higher throughout the world, but it is rare to cultivate rice during the dry season in Honduras because sufficient water is not available. Yields of 11 t ha^{-1} have been reported in parts of Asia where rice is grown during the dry season (De Datta 1981).

In Flores, rice is only grown during the rainy season. The fields are prepared for planting with two passes with a disc-plow shortly before planting. The fields are not leveled, pre-flooded or puddled, a process by which the soil structure is destroyed and percolation and permeability are diminished. Neither do most rice farmers construct soil bunds, which along with field channels, land leveling and proper tillage are considered the most important basic keys to good rice farming (Bouman et. al 2007). Farmers are reluctant to practice correct wet field preparation because of the supposed high cost of water. This is probably a misconception because good field preparation on level fields usually consists of puddling, or the compaction and destruction of soil structure for water retention improvement, and can be done with about 250 mm of water per hectare (Cabangon and Tuong 2000).

Planting occurs by direct dry seeding between May and July. The farmers harvest the rice between September and November. The reason that rice is only grown during the rainy season is because the Irrigation District believes it can only afford to provide supplemental irrigation to rice rather than provide all of its water needs during the dry season. Rice has such a high water demand that it is perceived to use too much water to be properly cultivated during the dry season.

The perception is probably not unfounded because rice, developed from semi-aquatic ancestors, is highly sensitive to water stress when soil moisture drops below saturation levels. Consequences of this stress can include decreased leaf area and production, closure of stomata and decreased photosynthesis, leaf senescence, increased root growth, reduced plant height, delayed flowering, reduced tillering, a reduced number of sprinklets and increased sprinklet sterility (Bouman et. al 2007). Soil moisture must be kept at saturation levels or these effects, some of which are irreversible, decrease yields.

CHAPTER FOUR - METHODS

This chapter presents the methods used to collect and analyze the data for this study. The first section describes the process and reasons for choosing individual fields for the data collection. The second section describes the method by which the fields were characterized by slope and general soil characteristics. The third section describes the design and collection of soil moisture data. The fourth section describes the calibration of the soil moisture meter. The fifth section describes how the samples were harvested, processed and weighed. The sixth section gives the questions used for the interviews on rice farming in Honduras, the farmers' methods, and their motivations for farming. The seventh and final section describes the processes used for data analysis.

4.1 Field Selection

The study used five rice fields divided between two farmers. Two farmers were selected because one could decide mid-season that he did not want to continue the study but data would still be collected. The study was limited to two farmers in order to limit coordinating conflicts, communication errors and the effects of management strategy and skill. It was always apparent that coordinating more than two farmers was going to be a difficult task in rural Honduras. Representatives of the local rice cooperative and irrigation office gave recommendations with whom to work. Meetings with each of them were then held concerning the purpose of the study, what would be required of them, and the benefits they would receive. It soon became apparent that Farmer 1 and Farmer 2 represented the best options because of the respect shown them by fellow farmers, their openness to change, their fields' proximity to town, the size of the fields, and the variety of slopes available. It was important to choose farmers with large cultivated areas in order to limit worries regarding yield losses as a result of trampling and 35 m^2 harvests in each field. One farmer did not want to partner with the study because he worried that he would lose too much from his one hectare farm. The chosen farmers, in contrast, farmed 55 and 74 hectares and did care about losing small amounts of rice to trampling along the transects and 35 m^2 harvests for yield calculations. Three fields of Farmer 1's and two of Farmer 2's were used. All five were rented by the farmers from local landowners.

From the fields rented by Farmer 1 and Farmer 2, individual fields were chosen in order to have a variety of slopes ranging from 0.5-6°. Adjoining fields were chosen where possible in order to limit soil differences. The three fields of Farmer 1's were adjoining and directly bordered Flores. The two fields of Farmer 2, however, were about five kilometers away and 0.5 kilometers apart from each other. This was necessary in order to get a field with a slope between 4-6°.

4.2 Field Characterization

Each field was characterized according to size, slope, and general soil characteristics. The size was measured in ArcGIS using GPS points taken on a Garmin 72h handheld device (Garmin International, Inc., Olathe, Kansas). The slope was measured using a Suunto clinometer (Suunto Oy, Valimotie, Finland). Multiple slopes were taken and averaged for each field; two or more slopes for the same field were only used on the same field if a part of the field had a noteworthy change in slope in comparison with the rest of the field. Soil characteristics for each field were measured by taking composite samples of fifteen individual soil cores of 6" and sending them to Zamorano Agricultural University in southern Honduras for analysis. Each sample was tested for texture, pH, organic matter, N_{total}, P, K, Ca, Mg, Na and cation exchange capacity. The Mehlich 3 extractant was used to determine values for P, K, Ca, and Mg (Mehlich 1984). The Walkley and Black Method was used to determine the percentage of organic matter (Walkley and Black 1934). The amount of N was determined as 5% of the value for organic matter. Texture was determined using the Bouyoucos Method (Bouyoucos 1936). Soil pH was measured using a 1:1 ratio of soil to water (Burt 2004). Fields 1, 2 and 3 of Farmer 1 each had one composite sample. Field 4 of Farmer 2 had three samples because of texture differences in the upper, middle and lower portions of the field. Field 5 of Farmer 2 had two samples because the two halves of the field were on different sides of a small hill.

4.3 Soil Moisture Measurements

Five transects oriented perpendicular to the contour were aligned on each field (Figures 4.1 and 4.2). Each transect was demarcated with 1.5 meter wooded stakes at each end. Within each transect, seven points were evenly spaced with an 8.25 ft buffer from each stake. The points were chosen on ArcGIS using the GPS points for each stake. Points were then located on the field by walking the appropriate number of chains (66 ft.).

Soil moisture measurements were taken using a Field Scout TDR 300 soil moisture meter probe (Spectrum Technologies, Inc., Plainfield, IL). It used 7.9” metal rods to measure volumetric water content (VWC). The three fields of Farmer 1, because of soil texture differences, were measured for VWC under the setting “High Clay.” The two fields of Farmer 2 were

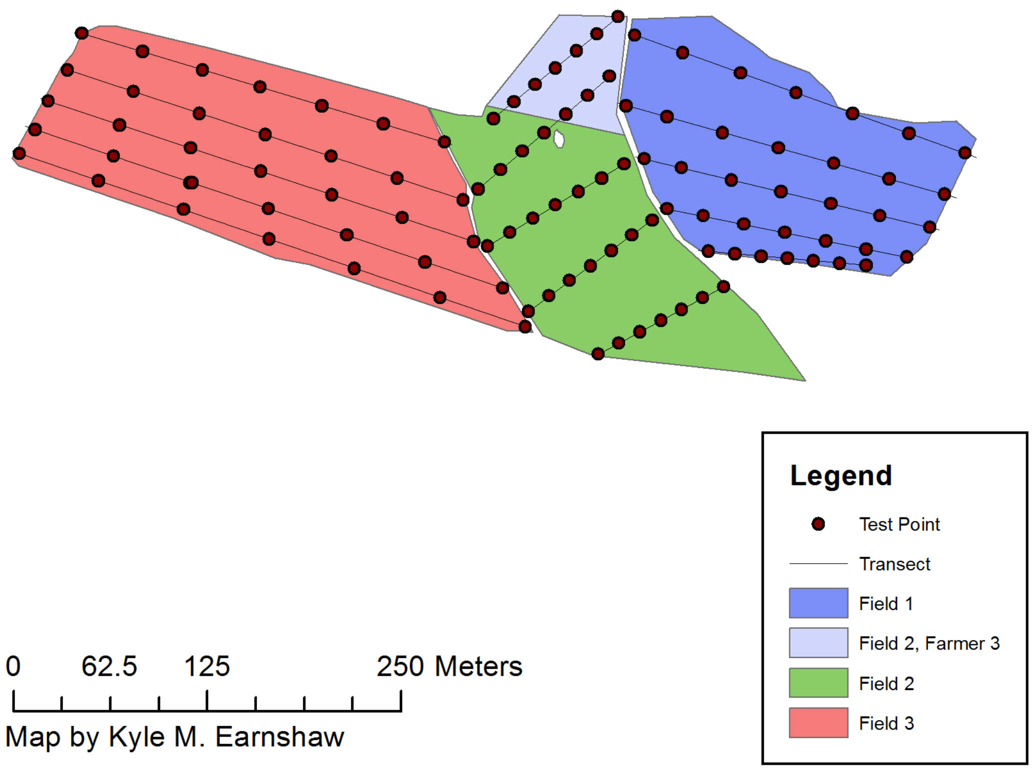

Figure 4.1. A schematic representation of the test points within the three fields of Farmer 1. The nine points that fell within Farmer 3's portion of Field 2 are also shown.

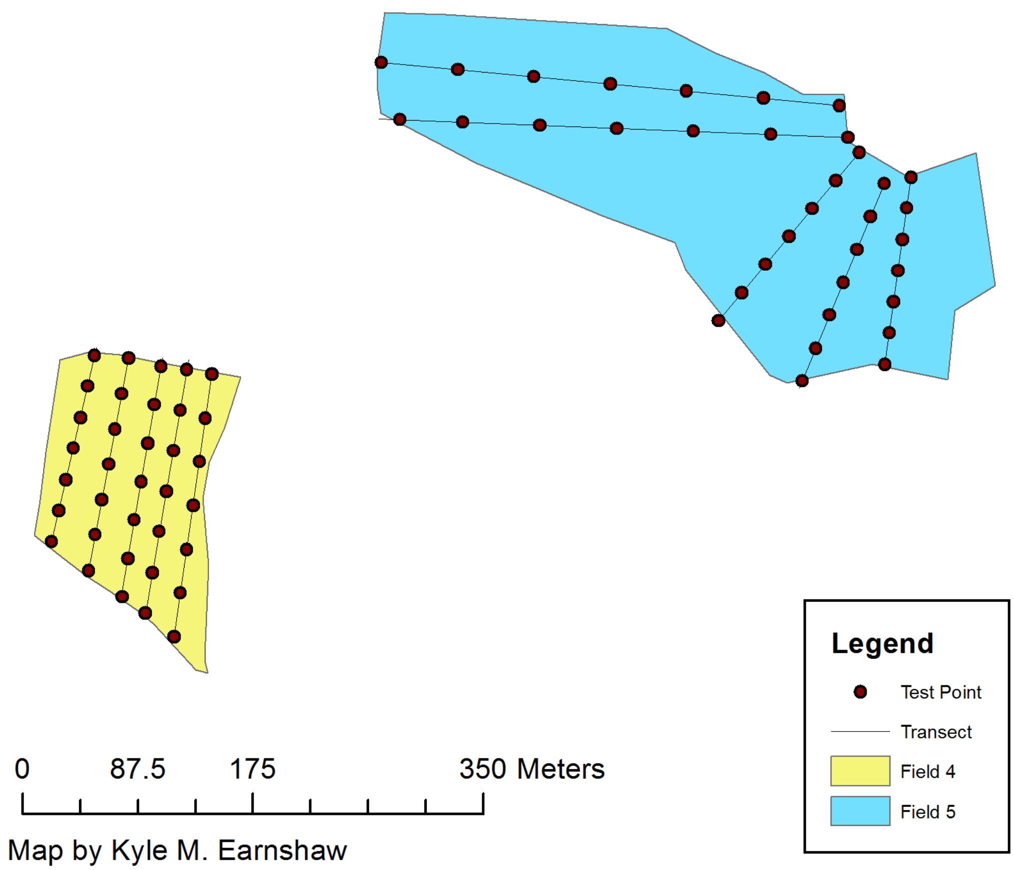

Figure 4.2. A schematic representation of the test points within the two fields of Farmer 2.

measured for VWC under the standard setting. At each point, the rods were pushed into the soil perpendicular to the slope. Measurements were only taken if the rods could penetrate the full 7.9" into the soil. If rocks or dry soil prohibited entry, attempts were made near the original site until successful.

The study called for soil moisture measurements during each of the major plant development stages of rice: tillering/vegetative, panicle initiation, flowering, maturation and a week before harvest. Once the rice entered each stage, measurements were taken one day, three days and six days after the successive irrigation. Irrigation scheduling problems and rain disrupted the schedule and measurements were taken during the tillering/vegetative, panicle emergence/flowering, post-flowering/pre-maturation and maturation stages (Table 4.1). This means that no measurements were taken during panicle initiation stage and only one set of measurements were taken during the mature stage. Even the modified schedule was not possible for all of the fields because of irrigation scheduling conflicts.

Table 4.1.

Sampling dates, slope, and transect/point are given with their abbreviations.

Stage/Category	Days after Irrigation	Abbreviation
Tillering/Vegetative	1	V1
Tillering/Vegetative	3	V2
Tillering/Vegetative	6	V3
Panicle Emergence/Flowering	1	P1
Panicle Emergence/Flowering	3	P2
Panicle Emergence/Flowering	6	P3
Post-Flowering/Pre-Maturation	1	R1
Post-Flowering/Pre-Maturation	3	R2
Post-Flowering/Pre-Maturation	6	R3
Mature	1	M1
Mature	3	M2
Mature	6	M3
Slope	-	SLP
Transect and Point	-	T-P

4.4 Soil Moisture Meter Calibration

In order to calibrate the moisture meter, soil cores were collected on the fields. One core of 6” x 8” was collected for Farmer 1’s three fields because they were adjacent. One core of 6” x 11” was also taken on each of Farmer 2’s fields. The cores were then fully saturated. When water was no longer freely flowing from the cores, soil moisture readings at the same setting as the field readings were taken and the cores were weighed to the nearest ounce every thirty minutes for three hours. Readings were then taken every hour until the seventh hour. Readings were then taken every 2nd to 4th hour until 46th hour. Readings were then taken once a day until the VWC readings stabilized near 0. Bulk density and total pore space were estimated and compared to the recorded data in order to validate it.

Figure 4.3. Parker and a Honduran helper situate the 1 m^2 PCV pipes on a test point in Field 1. Photo by Kyle M. Earnshaw

4.5 Yield Data

Within a week of the harvest for each field, one square meter was harvested at each point on each transect (Figure 4.3). All panicles were harvested and bagged (Figure 4.4). The bags were marked according to their field, transect and point numbers. The bags were then transported to the author's house and opened in order to allow the plants to dry. The bags of rice, with the grains still attached to the panicle, were dried for two days in the sun. The samples were threshed individually by stomping on them on a hard and clean ceramic surface. Each sample, then only the grains and some debris, was returned to the sample bag after threshing. When all the samples were threshed, the samples were then cleaned by pouring the samples from one bucket to another in front of a fan. After cleaning and drying each sample, each one was weighed using a 2,500 gram Pesola Medio-Line Spring Scale with 20 gram increments (Pesola, Inc., Kapuskasing, Ontario).

Figure 4.4. Kyle harvests rice for the yield data in Field 1. The picture shows one handful of panicles, one corner of the 1 m^2 PCV-pipes and the red plastic used to collect the samples. Photo by Kyle M. Earnshaw

4.6 Interviews

Each farmer was interviewed semi-formally, after getting IRB approval, according to surveying norms and using a survey approved by the Michigan Technological University Institutional Review Board (approval #M0778E; Bernard 1995). The oral consent statement read to the farmers can be found in Appendix C. The survey questions were:

- What challenges face rice producers in the Valley of Comayagua?
- Why don't farmers level their fields?
    - How much does it cost?
- Why don't farmers contour plow?
    - How much do they cost?
- Why don't farmers use soil bunds or other water retaining features?
    - How much do they cost?
- Do you own our fields?
    - If not, for how many years do you make your contracts with the land owner?
    - How much does it cost per year to rent a field?
- Why aren't contracts longer than ____ years?
- How much does it cost per manzana (6999 m^2) to produce rice?
    - How much do you spend in fertilizer each year?
    - In herbicide?
    - In labor?
    - In renting equipment?
    - In harvesting?
    - In transporting the rice?
    - Other costs?
- How many quintales (100 pounds of rice) are you losing do you think up slope versus down slope on _____ field?

- What technical assistance would you like to receive?
- Why do farmers plant rice rather than other crops?
- How do politics affect rice production?

I asked and wrote down the answers to these questions in Spanish before translating them into English.

4.7 Data Analysis

SAS (SAS Institute Inc., Cary, N.C.) was used to do the statistical analyses with the following procedures: PROC GLM, PROC CORR, and PROC TTEST (see Appendix B for code used). Analysis of variance (ANOVA) was used to test significance in soil moisture, slope, transect points and farmers on yield (Steel and Torrie 1960). Tukey's Studentized Range (HSD) was used to test the significance of differences in yields across fields, slopes and transect points (Steel and Torrie 1960). Correlations looked at slope, transect points and soil moisture at transect points for the different growth stages against yields (Steel and Torrie 1960). T-tests were used to determine significant difference between soil moisture tests with and without rain the night before (Steel and Torrie 1960). Results were declared significant at $P < 0.10$. P values are given throughout the results and discussion chapter. Finally, the Thornthwaite Method was used to develop a water balance model for Flores during normal and abnormally high precipitation years (Dunne and Leopold 1978).

CHAPTER FIVE - DATA

This section presents the soil moisture, slope and yield readings for each point of each field. Readings are given for soil moisture at each measured growth stage. Table 5.1 presents the data for Field 1. Table 5.2 presents the data for Field 2. Table 5.3 presents the data for Field 3. Table 5.4 presents the data for Field 4. Table 5.5 presents the data for Field 5.

This section also presents data collected for the soil moisture meter calibration (Figure 5.1).

Table 5.1.

Soil moisture, slope and yield data for all points in Field 1. See Table 4.1 for meaning of each variable.

T-P	V1	V2	V3	P1	P2	P3	R1	R2	R3	M1	M2	M3	SLP	Grams
1-1	37.7	36.3	36.6	41.4	37.2	28.5	34.1	30.2	37.2	46.4	27.1	19.3	5	820
1-2	41.4	44.5	41.7	53.1	40.8	44.7	42.5	38	43.3	45	34.1	25.7	5	880
1-3	47.8	45	54.5	42.2	56.8	59.6	60.1	50.3	45.9	44.5	40.3	36.6	5	920
1-4	45.3	49.5	41.9	45.3	43.3	41.9	45.3	39.1	48.1	41.7	30.5	27.4	3	660
1-5	46.4	51.2	47.3	44.5	45.6	44.2	48.7	37.2	45.3	41.1	36.1	28.5	3	760
1-6	48.7	46.4	48.1	53.7	47.8	48.9	45.6	44.7	49.8	50.9	38.3	30.2	3	920
1-7	42.2	41.4	59.3	40	47.3	53.4	51.5	45.6	47	60.7	46.7	44.2	3	860
2-1	41.1	40	41.7	46.1	38.9	36.9	42.5	36.3	40	35.5	34.7	26.5	5	1040
2-2	44.7	46.7	41.9	41.7	40	38.9	47.8	43.9	41.4	42.8	39.4	27.1	5	740
2-3	40.8	38.6	45.3	41.1	38.6	38.6	43.9	33.8	40.3	37.5	31.3	29.1	5	680
2-4	37.7	35.8	38.3	43.9	36.9	32.1	36.3	34.1	37.7	37.7	25.7	21.2	3	840
2-5	36.1	35.8	33.3	39.1	34.1	39.7	32.1	25.7	35.5	35.5	25.7	17.6	3	1000
2-6	34.7	43.9	36.3	38.3	30.7	34.4	34.9	29.6	36.6	30.2	24	19.8	3	880
2-7	40.3	60.4	42.8	36.3	39.7	43.3	40.5	38.6	50.1	40.5	35.5	32.4	3	800
3-1	44.7	41.4	41.7	43.9	43.1	45.9	43.3	39.7	38.9	38	37.7	22.9	3	860
3-2	41.1	36.3	43.1	40.5	38.3	41.1	41.7	38.3	41.4	43.1	32.4	29.1	3	960
3-3	43.3	41.9	45	40.5	42.5	39.7	43.3	39.7	44.7	43.3	38.6	19.5	3	580
3-4	45.3	42.2	49.2	42.5	45	43.9	43.3	41.7	45.3	45	40.8	29.1	3	880
3-5	40.3	44.7	40	41.9	40.8	39.1	41.9	40.3	44.2	35.8	32.1	23.2	3	860
3-6	40.8	40	43.1	42.2	40.3	33.5	48.9	40	46.1	41.9	35.5	24.9	3	780
3-7	45.3	41.4	44.7	42.5	41.1	39.4	42.5	39.1	45.9	42.2	37.5	28.5	3	1160
4-1	48.7	44.5	47	44.2	48.9	51.2	55.1	41.7	48.7	49.2	37.5	37.7	3	880
4-2	40.5	41.9	41.9	41.7	43.3	45.9	47.3	39.7	45.6	45.6	37.2	31.6	3	1080
4-3	39.1	41.1	43.3	38.3	40.3	39.7	43.6	34.7	42.8	44.5	35.8	17	3	960
4-4	59.3	47.5	44.2	48.9	42.2	54.3	52.9	46.1	42.5	40	23.7	25.4	3	880
4-5	43.6	43.1	47.5	54.5	40.5	55.7	52.6	39.4	43.9	46.4	32.1	20.9	3	960
4-6	50.3	45.3	50.1	47	48.4	58.7	56.8	46.1	48.9	52	42.5	20.7	3	940
4-7	51.5	57.9	54.3	54	54.3	54.3	51.7	53.4	57.1	51.5	43.3	48.1	3	980
5-1	45.3	45.6	46.7	43.6	43.6	43.9	48.9	41.1	45.3	39.7	42.5	33.3	3	620
5-2	46.4	46.4	45.9	45.3	47.5	49.8	53.1	44.5	49.8	44.7	45.9	40.3	3	960
5-3	47.5	47	51.7	47.3	46.1	65.7	57.1	43.1	54.8	47.5	45.3	40.5	3	980
5-4	49.5	47.3	47.8	48.4	46.4	55.1	53.1	43.9	48.1	44.7	46.4	31.3	3	1000
5-5	47.5	49.2	48.4	47.8	45.6	46.7	50.1	45.6	46.7	48.1	44.2	34.7	3	1040
5-6	54.3	49.2	52.9	48.9	51.2	51.7	62.1	50.6	50.3	55.9	41.4	39.4	3	1060
5-7	56.2	55.7	58.2	59.3	59.9	53.7	69.4	56.5	60.7	68.5	53.4	44.2	3	890

Table 5.2.

Soil moisture, slope and yield data for all points in Field 2. See Table 4.1 for meaning of each variable.

T-P	V1	V2	V3	P1	P2	P3	R1	R2	R3	M1	M2	M3	SLP	Grams
1-1	43.9	39.4	43.3	41.1	37.7	35.2	47.3	43.1	40.5	39.1	26.5	24.9	2.5	520
1-2	51.5	49.2	49.8	48.1	49.8	49.8	49.5	43.9	48.7	48.4	37.7	34.7	2.5	1000
1-3	47.5	49.5	48.1	45	46.1	44.5	51.2	44.2	49.8	49.8	41.7	34.4	2.5	1000
1-4	46.1	49.8	48.7	47.3	45.3	45	49.2	47.8	53.1	47	40.3	37.7	2.5	900
1-5	50.3	48.9	50.6	46.4	46.1	48.1	56.8	47.5	54.3	52.6	38.3	35.5	2.5	1320
1-6	48.1	46.1	48.7	48.1	54.3	45.3	49.2	47	56.2	50.9	32.1	38.6	2.5	980
1-7	58.2	54.3	57.1	56.2	51.7	55.1	57.6	51.7	59	60.1	41.1	37.7	2.5	880
2-1	36.9	31.6	35.2	31.3	31.9	34.4	40.3	26	30.5	33	20.4	21.8	2.5	520
2-2	40	37.2	44.7	39.7	40	38.6	42.8	30.5	35.5	33.3	24	24.9	2.5	740
2-3	44.5	46.4	47.5	45.3	43.9	39.1	44.5	36.6	48.9	45	35.5	31.9	2.5	1060
2-4	44.7	45.3	44.2	43.9	43.1	46.1	49.2	39.7	48.4	45.6	33.8	27.9	2.5	920
2-5	49.5	47.8	49.8	48.4	48.4	42.5	57.3	42.2	52.9	39.7	32.4	36.3	2.5	1080
2-6	45	47.5	51.2	50.1	47.5	47	59.9	47.3	52	50.6	38.9	30.5	2.5	820
2-7	57.3	55.7	61.5	54.3	52.9	48.7	59	55.7	61	48.1	41.9	38.3	2.5	780
3-1	40.3	36.9	38.9	40.5	38.6	36.1	44.2	32.1	40	36.6	30.7	27.1	2.5	700
3-2	46.1	45.6	45.9	38	41.9	44.7	48.4	41.9	44.7	43.1	37.5	33.8	2.5	900
3-3	46.4	44.5	46.4	50.1	42.5	38	47.8	39.1	42.2	38.9	29.1	28.2	2.5	800
3-4	51.2	48.7	49.5	47	46.7	42.8	54.8	44.5	54.8	43.3	35.8	32.7	2.5	1080
3-5	47.8	49.8	49.5	49.8	48.4	46.7	51.2	41.1	48.9	47	37.7	33.8	2.5	920
3-6	56.5	50.3	52	57.3	48.1	47	59.3	50.6	53.7	51.5	38	38	2.5	1020
3-7	47.5	49.8	53.4	48.1	49.5	50.3	52.6	49.2	57.6	53.1	45.3	44.7	2.5	1000
4-1	38.9	45.3	45.3	41.4	39.4	35.8	41.4	32.4	38.3	37.5	27.7	21.2	2.5	520
4-2	47.8	47.8	43.1	42.8	45.3	44.5	45.3	34.4	47.5	48.7	29.9	26.3	2.5	1040
4-3	44.7	59.3	49.8	43.6	43.9	45.6	48.7	46.1	48.1	50.1	33.8	29.1	2.5	860
4-4	61.5	54.3	64.1	62.4	59	59.9	75.8	62.4	69.1	71.3	53.1	42.5	2.5	620
4-5	55.9	55.7	51.7	48.7	52.3	57.1	64.6	53.4	49.5	57.3	43.1	40.5	2.5	400
4-6	48.4	45.9	48.7	48.7	50.3	54.3	53.7	46.4	59.3	48.7	47	47.5	2.5	580
4-7	44.5	43.6	43.6	41.9	44.5	46.4	52.3	41.9	48.7	44.5	38.6	35.2	2.5	660
5-1	42.8	45.3	46.7	43.1	43.6	43.1	45.3	41.9	42.5	39.7	36.1	31	2.5	1060
5-2	46.7	46.1	48.4	43.6	43.1	46.1	51.7	41.4	45.9	42.2	36.6	28.5	2.5	720
5-3	52	49.8	54	47.8	47.3	48.7	50.3	44.2	50.9	50.9	42.5	29.6	2.5	680
5-4	51.5	54	55.9	53.1	53.4	61.3	61.8	54.3	60.4	64.6	52	46.7	2.5	740
5-5	52.6	51.2	47.8	53.1	46.1	50.6	61.3	50.6	57.6	57.1	38.9	41.9	2.5	500
5-6	45.9	44.7	55.1	57.3	47.5	47.8	63.5	45.9	57.1	53.1	42.8	47.3	2.5	480
5-7	46.1	62.7	61	36.1	57.6	61.3	60.7	54	62.7	62.9	51.5	47	2.5	640

Table 5.3.

Soil moisture, slope and yield data for all points in Field 3. See Table 4.1 for meaning of each variable.

T-P	V1	V2	V3	P1	P2	P3	R1	R2	R3	M1	M2	M3	SLP	Grams
1-1	43.3	43.1	43.6	40.3	43.6	41.7	41.7	40	41.9	49.5	46.4	33	0.5	1000
1-2	41.9	40.5	43.9	37.5	41.7	34.9	46.4	37.7	44.2	33.3	25.4	27.9	0.5	900
1-3	45	42.5	47.3	42.8	45.6	39.1	48.9	44.7	48.1	62.1	45	32.7	0.5	1060
1-4	47.8	45.3	47	45.9	45.3	43.3	48.9	45.3	52.3	49.8	49.8	32.1	0.5	820
1-5	40.5	39.1	43.6	39.1	37.5	32.4	49.5	42.8	44.2	39.1	37.7	19.3	0.5	820
1-6	45.3	40.3	49.5	44.5	42.5	42.2	48.4	41.7	46.7	42.5	45.9	29.9	0.5	820
1-7	44.2	34.1	45	43.3	45.6	35.5	43.9	47	46.7	43.3	30.7	34.7	0.5	900
2-1	36.1	35.8	39.4	38.6	38.6	34.1	41.4	35.8	35.2	32.4	25.1	23.5	0.5	920
2-2	45.6	38	43.3	45	42.8	43.9	45.3	43.6	37.2	41.1	35.5	27.9	0.5	940
2-3	36.6	33.5	38.9	38.6	38.6	34.4	39.1	37.2	43.1	38.3	30.7	27.4	0.5	1100
2-4	41.9	40.8	42.2	41.7	37.7	32.1	41.9	36.6	42.5	48.9	29.3	31	0.5	920
2-5	43.9	38.3	40.5	41.4	40.8	34.7	47.5	38.6	39.4	45.3	30.2	28.8	0.5	1040
2-6	40.5	42.5	42.2	40.3	38.6	36.3	40.5	38.9	38.6	34.1	28.8	25.7	0.5	1080
2-7	41.7	40	41.4	40.3	40.5	37.5	48.1	39.4	42.8	36.3	32.1	28.8	0.5	1060
3-1	40.8	39.4	41.4	40.3	40.8	36.3	45	40.3	43.3	38.3	31.9	26.5	0.5	980
3-2	45.9	43.6	43.9	43.3	42.2	40.3	46.4	41.9	44.5	41.4	35.2	27.1	0.5	740
3-3	40.3	40.8	41.9	41.7	40.3	36.3	42.8	35.8	41.1	38.6	31.9	26.3	0.5	860
3-4	45.3	41.9	46.1	42.5	40.5	39.4	46.1	46.7	47	40	38.9	28.8	0.5	1080
3-5	46.1	46.4	45.3	44.5	44.7	43.6	46.7	41.4	45.3	42.2	37.7	29.9	0.5	1020
3-6	38.6	43.6	45.6	43.3	41.9	39.4	43.9	38	40.3	41.7	35.8	31.3	0.5	980
3-7	43.3	41.1	42.2	43.6	43.3	40	50.1	38.6	43.6	41.1	33.3	31	0.5	1160
4-1	43.1	40	44.7	40.8	40.8	33.8	40.5	36.3	42.2	38	33.5	27.4	0.5	780
4-2	42.8	42.2	44.7	41.7	44.7	41.4	45.3	42.8	44.2	40.3	35.8	31.6	0.5	700
4-3	46.1	43.9	47	47.3	46.1	42.8	48.7	39.1	44.7	43.9	38	29.6	0.5	1180
4-4	48.7	39.7	43.9	43.3	45.3	43.1	48.4	40	53.7	44.2	31	32.1	0.5	1320
4-5	46.4	43.3	45	45.9	42.8	40	47.5	43.3	45.9	44.7	31.9	32.1	0.5	1200
4-6	42.8	41.4	40.5	41.9	39.7	36.9	40	36.9	41.4	39.1	30.2	27.4	0.5	1240
4-7	44.2	43.1	45.3	43.6	43.1	40.8	48.7	41.1	48.1	43.1	32.4	30.2	0.5	900
5-1	36.3	35.8	38.6	35.8	36.1	33	37.5	34.1	36.9	29.1	17.9	22.1	0.5	820
5-2	36.3	36.6	39.7	37.7	37.5	34.4	38.9	34.9	38.3	33.3	21.2	23.7	0.5	720
5-3	36.6	40.5	40.5	37.2	34.7	30.5	40.3	37.2	40.5	37.7	32.1	27.4	0.5	880
5-4	38.9	41.9	40.8	36.9	37.7	34.9	40	36.1	45.3	38.3	27.4	26.5	0.5	1100
5-5	46.1	43.6	45.3	41.7	40.5	40.8	48.1	41.9	45.3	37.7	27.7	30.2	0.5	860
5-6	42.8	41.4	45.9	40.8	41.7	37.2	40.8	36.9	40.3	36.9	28.5	26.5	0.5	940
5-7	41.9	42.2	40.8	43.6	41.1	39.1	37.2	39.1	44.2	39.7	30.2	25.4	0.5	1220

Table 5.4.

Soil moisture, slope and yield data for all points in Field 4. See Table 4.1 for meaning of each variable.

T-P	V1	V2	V3	R1	R2	M1	M2	M3	SLP	Grams
1-1	66.5	78.2	73.7	64.8	73.2	63.4	38.4	65.1	3	400
1-2	74	71.8	71.5	73.4	64.3	67.9	60.7	49	3	460
1-3	67.6	50.9	71.8	68.7	72	60.4	37.9	32.3	3	420
1-4	50.1	40.1	41.5	35.4	37.3	33.7	32.6	29.8	3	600
1-5	51.8	41.8	45.7	45.1	33.4	31.2	33.4	31.8	3	420
1-6	62.9	62.6	44.5	42	55.9	59.5	43.2	47.3	3	660
1-7	77.3	82.3	75.4	68.7	67	58.4	60.4	69.8	3	900
2-1	64	59	62	59.3	55.1	50.4	54.5	47.3	3	820
2-2	49.8	53.4	53.2	52.3	48.2	47	53.4	46.8	3	780
2-3	48.7	50.1	51.2	54.3	38.7	44	36.2	35.7	3	740
2-4	42.6	56.2	58.7	36.2	34.5	31.2	28.2	35.9	3	600
2-5	49	60.1	41.5	39	40.7	41.5	44.8	34.3	3	460
2-6	55.7	70.7	63.4	43.4	61.5	58.2	43.4	62.3	3	560
2-7	51.5	69	69	44.3	72.3	49.5	47.6	57	3	760
3-1	57.6	56.8	52	50.9	47.9	44	47.9	43.7	3	780
3-2	56.5	45.4	45.9	41.2	72.6	39.5	37.3	34	3	720
3-3	46.8	50.1	51.5	49.5	45.7	40.9	39	34.5	3	680
3-4	54	41.5	42.9	30.7	39.3	31.5	34.8	34.5	3	600
3-5	42.3	39.3	39	27	35.1	29	34.5	31.2	3	680
3-6	39.3	39	38.4	25.1	50.9	25.9	38.2	34.3	3	720
3-7	52.3	71.8	51.8	61.2	55.7	42.6	52	56.8	3	1160
4-1	54.3	54.5	57.3	57	59.3	49.5	52.3	47.3	3	860
4-2	40.9	41.5	45.7	46.2	43.2	35.9	42.9	35.9	3	640
4-3	53.4	52.6	56.8	36.2	52	48.4	48.7	40.7	3	560
4-4	39.5	41.8	39.8	27.3	37	26.8	39.3	38.4	3	840
4-5	41.2	44.5	42	30.1	42.9	32.6	38.4	34.5	3	1100
4-6	38.4	39.3	36.8	18.7	15.9	25.1	35.4	34	3	920
4-7	66.5	80.4	80.9	54	67.9	51.2	60.7	65.4	3	760
5-1	59.3	57.3	65.7	73.4	65.7	50.1	54.8	53.2	3	660
5-2	75.7	75.9	74.8	55.1	68.2	66.8	69.5	61.8	3	460
5-3	46.8	56.5	49.5	23.7	46.5	39.8	30.9	24.8	3	720
5-4	44.3	44.3	42.6	39	40.4	50.4	49	39.8	3	720
5-5	35.1	41.5	38.7	21.8	16.2	26.2	22.3	28.7	3	680
5-6	35.9	38.2	38.4	19.3	24.3	25.9	30.7	22.3	3	420
5-7	45.9	49	49	25.7	45.1	34.5	38.2	33.7	3	940

Table 5.5.

Soil moisture, slope and yield data for all points in Field 5. See Table 4.1 for meaning of each variable.

T-P	V1	V2	V3	M1	M2	M3	SLP	Grams
1-1	55.9	60.1	57.3	54.3	49.3	51.2	6	920
1-2	35.7	37.9	36.5	35.4	32	31.5	6	80
1-3	39	38.2	38.2	37.9	40.9	39.3	6	620
1-4	69.5	74.3	70.1	60.9	60.7	69	4	1100
1-5	80.7	80.9	77.6	44.3	42.6	38.2	4	800
1-6	44.3	41.5	72	37	37	38.7	4	780
1-7	62	67.9	65.4	61.8	61.2	60.4	4	860
2-1	41.5	43.4	42.6	34	46.5	37	6	400
2-2	55.9	46.5	58.2	50.4	50.4	40.4	6	200
2-3	70.4	57	52.9	54.8	62	53.2	6	620
2-4	45.1	42.3	41.2	60.1	64.8	36.2	4	440
2-5	71.8	53.7	62.3	67.6	56.2	54.5	4	860
2-6	69.3	79.3	73.7	82	77.9	80.4	4	560
2-7	67	68.4	73.2	75.7	79.3	74.8	4	1200
3-1	42.9	43.4	42	43.7	44.8	45.1	4	1000
3-2	60.9	62.9	62.6	61.2	67	68.2	4	340
3-3	56.8	60.1	69.8	56.2	54.5	51.2	4	320
3-4	74.5	70.9	69.3	62.3	64	69	4	320
3-5	44.5	42	48.7	42.3	38.7	40.1	4	180
3-6	49.8	51.8	47.9	40.9	42.3	42.6	4	240
3-7	45.9	45.7	47.3	43.2	40.1	42.9	4	680
4-1	34.8	34	39	41.2	35.7	35.1	4	260
4-2	56.2	42	45.7	39	48.2	38.7	4	340
4-3	50.1	40.7	39.8	39.3	39.5	40.7	4	320
4-4	72.6	49.3	42.9	41.2	43.4	39.3	4	740
4-5	71.8	69.8	69	57.3	68.4	59.5	4	300
4-6	78.7	47.3	70.1	64.5	64.3	64	4	860
4-7	85.4	78.2	77.9	74.5	68.4	74.5	4	960
5-1	43.2	38.7	42	28.7	28.4	29	4	120
5-2	47.3	53.2	49.5	61.8	47	62.3	4	140
5-3	50.9	42.3	43.4	35.7	39	36.5	4	460
5-4	74.8	74.8	58.7	48.2	44	57.6	4	340
5-5	76.5	75.9	69.5	54.3	51.2	48.7	4	540
5-6	35.4	34.3	34.3	25.4	21.2	22.3	4	540
5-7	78.4	67.9	81.8	68.2	69	62.3	4	840

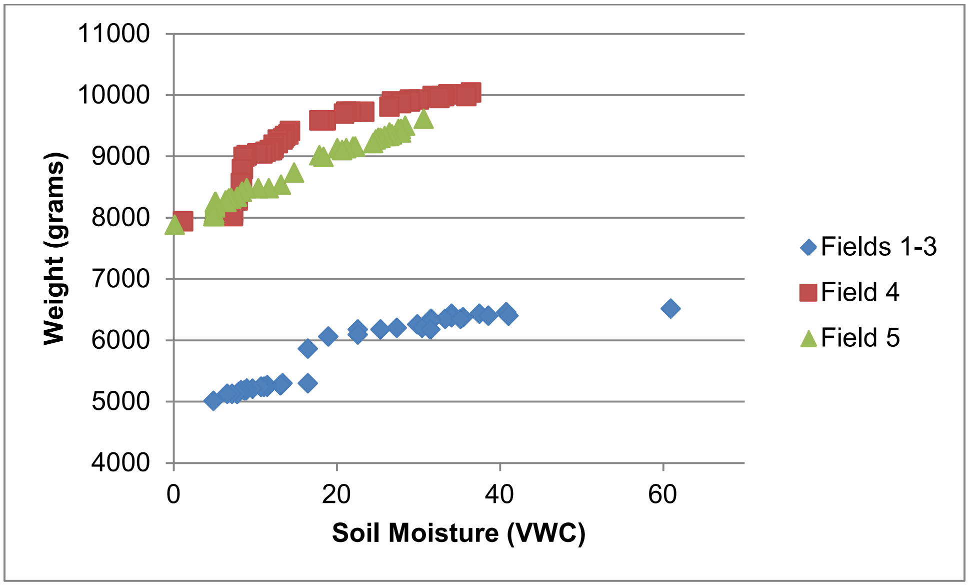

Figure 5.1. Soil moisture (VWC) is compared with weight for the three soil cores taken in order to calibrate the soil moisture meter

CHAPTER SIX – RESULTS AND DISCUSSION

This chapter opens with descriptions of each field used in the study based on the results of composite soil samples taken in the spring of 2011 and analyzed at Zamorano Agricultural University in southern Honduras. It then presents the results of the calibration of the soil moisture meter. The results of ANOVA, correlation, and regression analyses follow. The analyses are on soil moisture vs. yield, soil moisture vs. yield at transect point, soil moisture vs. slope, transect point by farmer vs. yield, farmer vs. yield and slope vs. yield. The results of the analyses are starting points for discussions on 1) transect point, soil moisture and slope, 2) the differences in yields by farmer, 3) the effect of farmer practices, 4) the effect of land tenure on soil conservation practices and water management and 5) the logic of using field studies rather than research plots.

6.1 Field Characterization

This section presents the characteristics of each field individually. Basic soil composition, nutrient levels, cation exchange capacity, slope and observations are given. The field characterization ends with details on planting and harvesting dates.

Each field had at least one composite soil sample analyzed at Zamorano Agricultural University in Honduras. The three fields of Farmer 1 each had one sample analyzed while the two fields of Farmer 2, Fields 3 and 4, had three and two composite samples analyzed, respectively.

Field 1's texture was 40% sand, 34% silt and 26% clay (Figure 6.1). It had a pH of 6.1. The percentages of organic matter and N_{total} were 3.4% and 0.2% respectively. Phosphorous measured 24 mg kg^{-1}, potassium 1368 mg kg^{-1}, calcium 2480 mg kg^{-1}, magnesium 210 mg kg^{-1} and sodium 470 mg kg^{-1}. The cation exchange capacity was 36 meq^{+} $100g^{-1}$. Slopes here were not uniform and included slopes of 5º and 3º degrees. The first three points of Transect 1 were recorded as 5º slopes. One should also note that the first points of each transect were not uniform in their altitude; point one of transect one was the highest point on the field and all other points were lower than it.

Figure 6.1. Farmer 1's Field 1. Transect Point 1-1 was located in the far corner in the center of the photo. Photo taken by Kyle M. Earnshaw

Field 2's texture was 38% sand, 34% silt and 28% clay (Figure 6.2). It had a pH of 6.4. The percentages of organic matter and N_{total} were 3.4% and 0.2%, respectively. Phosphorous measured 18 mg kg^{-1}, potassium 1320 mg kg^{-1}, calcium 2710 mg kg^{-1}, magnesium 280 mg kg^{-1} and sodium 355 mg kg^{-1}. The cation exchange capacity was 35 meq^{+} $100g^{-1}$. The slope on this field was 2.5 °. This field presented the most problems operationally. When the field was chosen, the farmer stated the boundaries of the field, but added that an adjacent portion was also open to use for the study. This part was included because it allowed for sampling of the lowest area of the field where water collected. As the study progressed, it became apparent that this other portion was under the management of another farmer. It had its own field workers and irrigation and fertilization schedules. Large differences in plant height, vigor, and weed competition were observed in this section. Nine points out of the total 35 were in this adjacent field.

Figure 6.2. Farmer 2's Field 2. The nine points of Farmer 3 were located in the drainage area of this field behind the trees in the center of the photo. Photo by Kyle M. Earnshaw

Field 3's texture was 40% sand, 36% silt and 24% clay (Figure 6.3). It had a pH of 6.1. The percentages of organic matter and N_{total} were 2.6% and 0.1%, respectively. Phosphorous measured 19 mg kg^{-1}, potassium 1176 mg kg^{-1}, calcium 2280 mg kg^{-1}, magnesium 240 mg kg^{-1} and sodium 213 mg kg^{-1}. The cation exchange capacity was 19 meq^{+} 100g^{-1}. The slope on this field was calculated at 0.5º. It was the most uniform of the fields, although it did have a large *Tabebuia rosea* (Bertol.) DC. growing on the upper portion. None of the test points were directly below its branches. The field was not leveled; depressions could have formed in portions of the field, raised soil moisture upslope and increased variation of crop growth and yields (Bouman et. al 2007).

Figure 6.3. Farmer 3's Field 3. Transect points 7 were located at the far end of the photo. Photo by Kyle M. Earnshaw

Field 4 had composite soil samples taken on the upper third, the middle third and the lower third of the field (Figure 6.4). The upper portion's texture was 58% sand, 20% silt and 22% clay. It had a pH of 6.1. The percentages of organic matter and N_{total} were 1.7% and 0.1%, respectively. Phosphorous measured 6 mg kg^{-1}, potassium 510 mg kg^{-1}, calcium 1580 mg kg^{-1}, magnesium 230 mg kg^{-1} and sodium 173 mg Kg^{-1}. The cation exchange capacity was 17 meq^{+} $100g^{-1}$. The middle third had a texture of 66% sand, 20% silt and 14% clay. It had a pH of 5.6. The percentages of organic matter and N_{total} were 1.7% and 0.1%, respectively. Phosphorous measured 4 mg kg^{-1}, potassium 310 mg kg^{-1}, calcium 970 mg kg^{-1}, magnesium 110 mg kg^{-1} and sodium 130 mg kg^{-1}. The cation exchange capacity was 8 meq^{+} $100g^{-1}$. The bottom third had a texture of 64% sand, 20% silt and 14% clay. It had a pH of 6.0. The percentages of organic matter and N_{total} were 2.1% and 0.1%, respectively. Phosphorous measured 4 mg kg^{-1}, potassium 228 mg kg^{-1}, calcium 1030 mg kg^{-1}, magnesium 90 mg kg^{-1} and sodium 143 mg kg^{-1}. The cation exchange capacity was 8 meq^{+} $100g^{-1}$. This field had a slope of 3°. The biggest complication on this field regarding field characteristics resulted from the varying texture up slope, mid slope and down slope. The middle portion often presented difficulties with soil moisture measurements because of rocks and hard ground. The soil moisture probes would not enter the ground at some points until a site up to two feet away was found where the soil moisture probes would not bend.

Figure 6.4. Farmer 2's Field 4. Multiple photos were combined to give a view of the entire field. Photos by Kyle M. Earnshaw

As it was on a small hill, composite soil samples were taken on both sides of Field 5 (Figures 6.5 and 6.6). The texture on the larger side was 54% sand, 24% silt and 22% clay. It had a pH of 6.2. The percentages of organic matter and N_{total} were 2.8% and 0.1%, respectively. Phosphorous measured 4 mg kg^{-1}, potassium 418 mg kg^{-1}, calcium 1660 mg kg^{-1}, magnesium 160 mg kg^{-1} and sodium 180 mg kg^{-1}. The cation exchange capacity was 32 meq^{+} $100g^{-1}$. The texture on the smaller side was 52% sand, 20% silt and 28% clay. It had a pH of 5.68. The percentages of organic matter and N_{total} were 2.8% and 0.1%, respectively. Phosphorous measured 5 mg kg^{-1}, potassium 348 mg kg^{-1}, calcium 1520 mg kg^{-1}, magnesium 230 mg kg^{-1} and sodium 130 mg kg^{-1}. The cation exchange capacity was 15 meq^{+} $100g^{-1}$. The first three points on Transects 1 and 2 on this field had average slopes of 6°, but the rest of the points on those transects and the three transects on the other side of the field had average slopes of 4°. High quantities of rocks made soil moisture readings difficult to obtain on the smaller portion of the hill because the soil moisture probes could not enter the soil.

Figure 6.5. Farmer 2's Field 5. Irrigation water is shown entering the smaller side of the field. In order to irrigate the larger portion, the water had to be directed to the right along the crest of the hill. Photo by Kyle M. Earnshaw

Figure 6.6. Farmer 2's Field 5 is seen from a nearby road. The larger portion of the field runs from above the solitary tree in the field down the hill to the left. Photo by Kyle M. Earnshaw

Farmer 1 planted his rice on 9 June, 2010 and harvested on 20 October, 2010, 134 days after planting. Farmer 2 planted his rice on 5 July, 2010 and harvested on 20 November, 2010, 139 days after planting.

6.2 Soil Moisture Meter Calibration Results

The results from the soil moisture calibration readings suggest that the VWC readings taken with the soil moisture meter were correct. Fields 1-3 were assigned a bulk density of 1.35 g $cm^{3\ -1}$ and a percent pore space of 44% with the accepted average of 2.65 g $cm^{3\ -1}$ used for particle density (Table 6.1) (Foth and Turk 1951). The bulk density was estimated by using a number slightly larger than the upper limit for bulk density in fine-textured soils (Foth and Turk 1951). Percent pore space was estimated by assuming a 5% reduction in pore space because of compaction (Miller and Donahue 1990). Fields 4 and 5 were given bulk densities of 1.5 g $cm^{3\ -1}$ as moderately sandy loams and percent pore spaces of 42% accounting for 5% compaction of pore space (Foth and Turk 1951; Miller and Donahue 1990). The results suggest that the VWCs measured by the moisture meter were correct.

Table 6.1.

Data on calculated soil properties are given with measured values for field capacity (FC) and dry soil volumetric water contents (VWC) to show similarity between measured and calculated values

	Field 1-3	
Total Measured Weight (g)	Calc. Tot. Weight (g)	Soil Moisture FC (VWC)
6515	6636	61
Total Dry Weight (g)	Calc. Dry Weight (g)	Soil Moisture Dry (VWC)
5011	5004	4.9
	Field 4	
Total Measured Weight (g)	Calc. Tot. Weight (g)	Soil Moisture FC (VWC)
10037	9786	36.5
Total Dry Weight (g)	Calc. Dry Weight (g)	Soil Moisture Dry (VWC)
7939	7646	1.2
	Field 5	
Total Measured Weight (g)	Calc. Tot. Weight (g)	Soil Moisture FC (VWC)
9612	9786	30.7
Total Dry Weight (g)	Calc. Dry Weight (g)	Soil Moisture Dry (VWC)
7883	7646	0.18

6.3 Results of Analyses

This section presents the results of analyses regarding soil moisture, transect point, slope, yield, farmers and their interactions.

6.3.1 Soil moisture vs. Yield

Moisture data was analyzed for each farmer separately because different moisture settings on the moisture meter were used for the fields of Farmer 1 and Farmer 2. This was because Farmer 1 had higher clay contents. The differences in clay, however, were only from 0% to 14% greater depending on the field and the location on the field. The setting on the moisture meter changed the VWC reading enough that the soil moisture data set could not be confidently combined. The farmers were compared based on the analysis' results.

Moisture content did not have a significant effect on yields in Farmer 1's fields (Table 6.2; Figures 6.7 through 6.9). Moisture content was statistically significant but weakly so when looking at Farmer 2's fields (Table 6.3; Figures 6.10 and 6.11). Soil moisture content was not correlated with yields for Farmer 1 and Farmer 2 except for a few spurious instances. Moisture content was not a driving force in yield differences.

6.3.2 Soil moisture vs. Yields at transect Point

Soil moisture content changed significantly on Farmer 1's ($p < 0.0001$) and Farmer 2's ($p = 0.0868$) fields based by transect point (Table 6.2 and Table 6.3). For Farmer 1, statistical significance changed only slightly with testing date. For Farmer 2, however, testing date affected significance (Table 6.3).

For Farmer 1, transect point is highly correlated with soil moisture content, but yields are not (Table 6.2). The correlations for Farmer 1 did not change when Farmer 3's nine points on Field 2 were or were not included in the analysis. Farmer 2's data shows low correlations of soil moisture content with yields and transect points (Table 6.3). On both fields soil moisture content increased as transect points increased, but it explained little of the yield data on either field.

Table 6.2.

Correlation between soil moisture and independent variables by growth stage on Farmer 1's fields. The top value for each stage is the R-value. The value in parentheses is the p-value. * = significant value at α=0.1. See Table 4.1 for meaning of each growth stage variable.

Growth Stage	Yield	Transect Point
V1	-0.0321	0.2992
	(0.7449)	(0.0019*)
V2	-0.1231	0.3597
	(0.2108)	(0.0002*)
P1	-0.0314	0.3295
	(0.7504)	(0.0006*)
P2	-0.0393	0.3449
	(0.6907)	(0.0003*)
P3	-0.0957	0.2788
	(0.3315)	(0.004*)
R1	-0.1839	0.3199
	(0.0604*)	(0.0009*)
R2	-0.0812	0.4006
	(0.41)	(<0.0001*)
M1	-0.0804	0.3399
	(0.4152)	(0.0004*)
M2	-0.08	0.2695
	(0.4175)	(0.0054*)
M3	-0.069	0.3608
	(0.4837)	(0.0001*)

Table 6.3.

Correlation between soil moisture and independent variables by growth stage on Farmer 2's fields. The top value for each stage is the R-value. The value in parentheses is the p-value. * = significant value at α=0.1. See Table 4.1 for meaning of each growth stage variable.

Growth Stage	Yield	Transect Point
V1	0.1567	0.1508
	(0.1952)	(0.2127)
V2	0.2183	0.2389
	(0.0694*)	(0.0464*)
V3	0.1904	0.198
	(0.1144)	(0.1002)
R1	-0.1121	-0.4221
	(0.5216)	(0.0115*)
R2	-0.079	-0.2242
	(0.6521)	(0.1954)
M1	0.0906	0.0774
	(0.456)	(0.5242)
M2	0.2076	0.1246
	(0.0848*)	(0.3042)
M3	0.2056	0.2062
	(0.0879*)	(0.0868*)

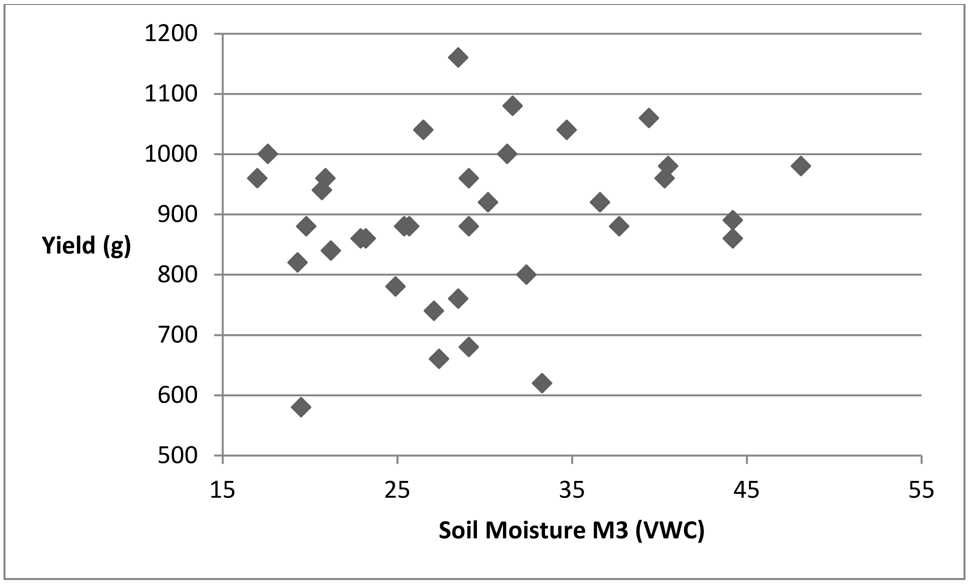

Figure 6.7. Yields (grams) for a given soil moisture for the third sampling day of the mature stage on Field 1. VWC = Volumetric Water Content.

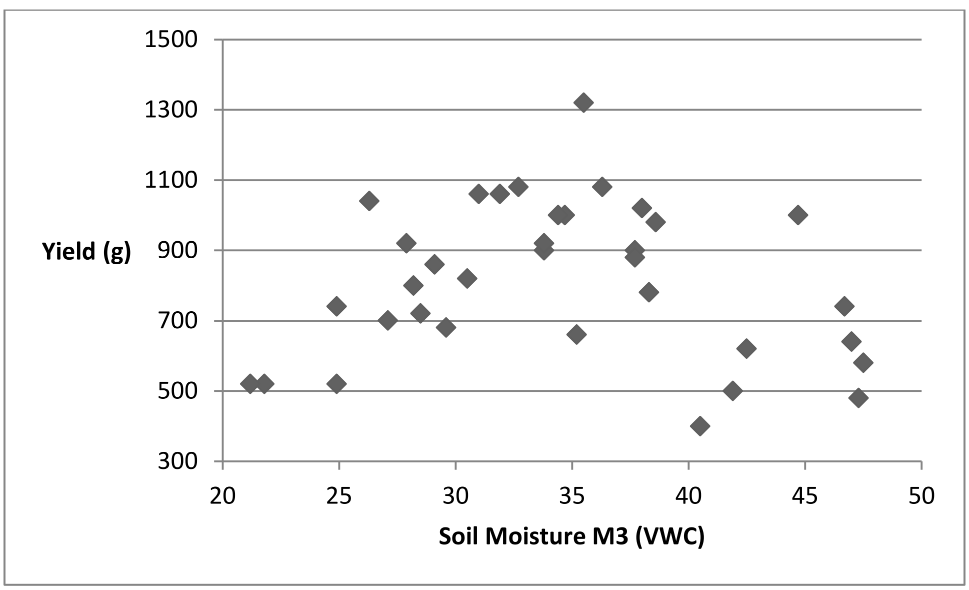

Figure 6.8. Yields (grams) for a given soil moisture for the third sampling day of the mature stage on Field 2. VWC = Volumetric Water Content.

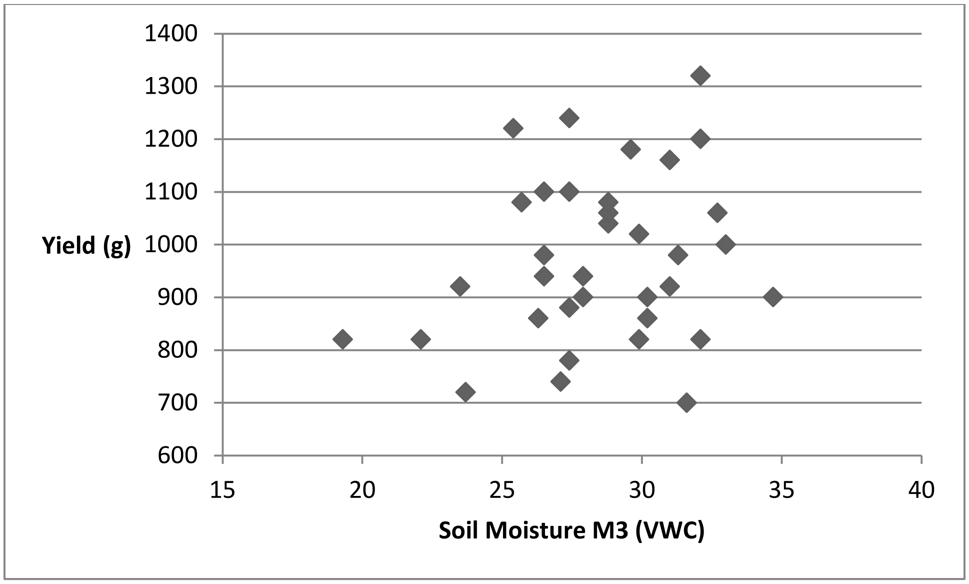

Figure 6.9. Yields (grams) for a given soil moisture for the third sampling day of the mature stage on Field 3. VWC = Volumetric Water Content.

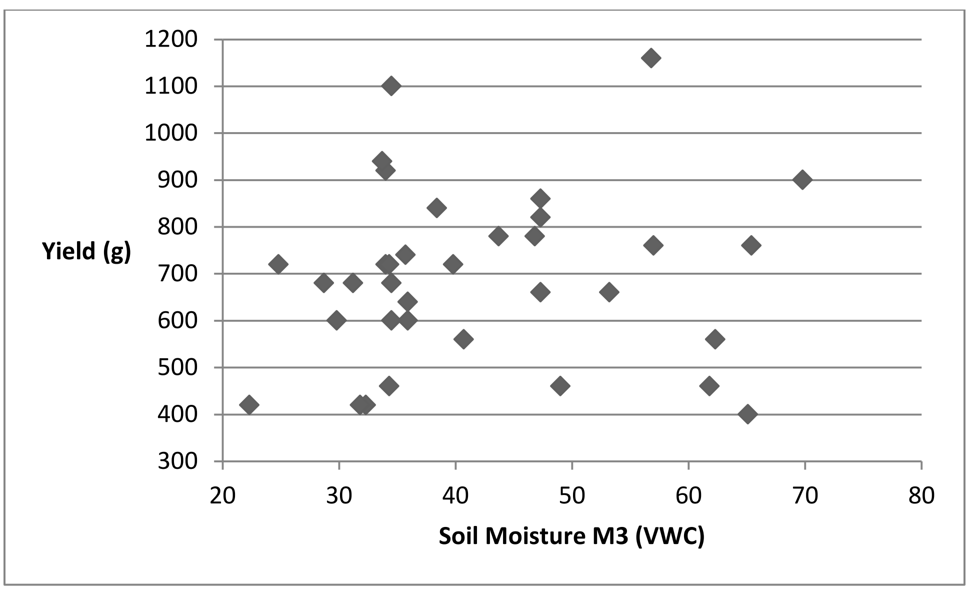

Figure 6.10. Yields (grams) for a given soil moisture for the third sampling day of the mature stage on Field 4. VWC = Volumetric Water Content.

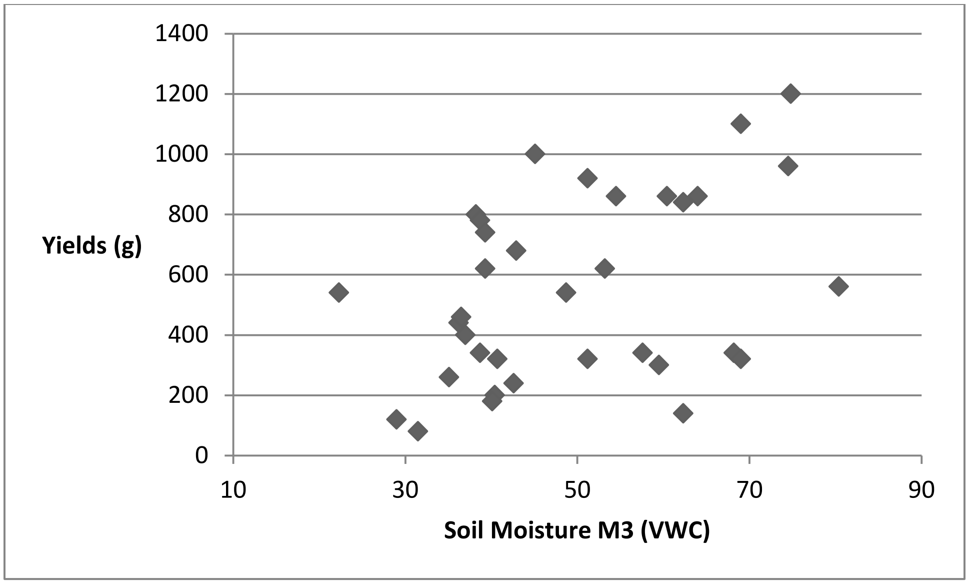

Figure 6.11. Yields (grams) for a given soil moisture for the third sampling day of the mature stage on Field 5. VWC = Volumetric Water Content.

6.3.3 Soil moisture vs. Slope

It should be noted that this study showed no correlation between slope and soil moisture on Farmer 2’s fields, possibly because of the near constant irrigation on his fields. The study also showed significant correlations between all but one soil moisture testing date and slope on Farmer 1’s fields, but the trend was negative. This meant that as slope increased, the soil moisture increased as well. This is counter intuitive and does not agree with what is known about soil hydrology (Dunne and Leopold 1978). This could have been because the individual topography of Farmer 1’s three fields and the difficulty of differentiating between 2.5º and 3º average slopes with a clinometer.

6.3.4 Transect Point and Fields vs. Yield

Transect point and field significantly affected yields ($p < 0.0001$, $\alpha=0.1$). Tukey's Studentized Range (HSD) tests were run on the transect and field data for yields (Tables 6.4 and 6.6). Yields were significantly affected by both transect point ($p = 0.0040$) and field ($p = <0.0001$). The interaction between them was not significant ($p = 0.1450$) unless the 9 extra points from Field 2 were removed ($p = 0.0622$). Field was the primary explanatory variable for yield for both data sets according Tukey's Studentized Range (HSD) Test.

Yields generally increased from one point to the next down the transect (Table 6.4), especially on Fields 4 and 5 (Figures 6.12 through 6.16). The lowest points, points 4-7, along each transect have higher yields than the points higher up in each field (points 1-3). A yield gradient is exhibited and point 7 is significantly different than points 1-3 according to Tukey's test (HSD). This shows that the tops of fields have lower yields than the bottoms.

Table 6.4.

Mean values of yield in grams for transect points for all five fields. The same letter indicates no significant difference between transect yields using Tukey's test for significant difference. Transect point 7 is significantly different than points 1-3 ($\alpha = 0.1$.). A general gradient of yields is also noted down the slope. N=174.

Transect Point	Mean Yield (g)	Mean Yield (t ha^{-1})
7	918	4.59[a]
4	802	4.01[a,b]
5	792	3.96[a,b]
6	791	3.96[a,b]
3	762	3.81[b]
1	730	3.65[b]
2	687	3.44[b]

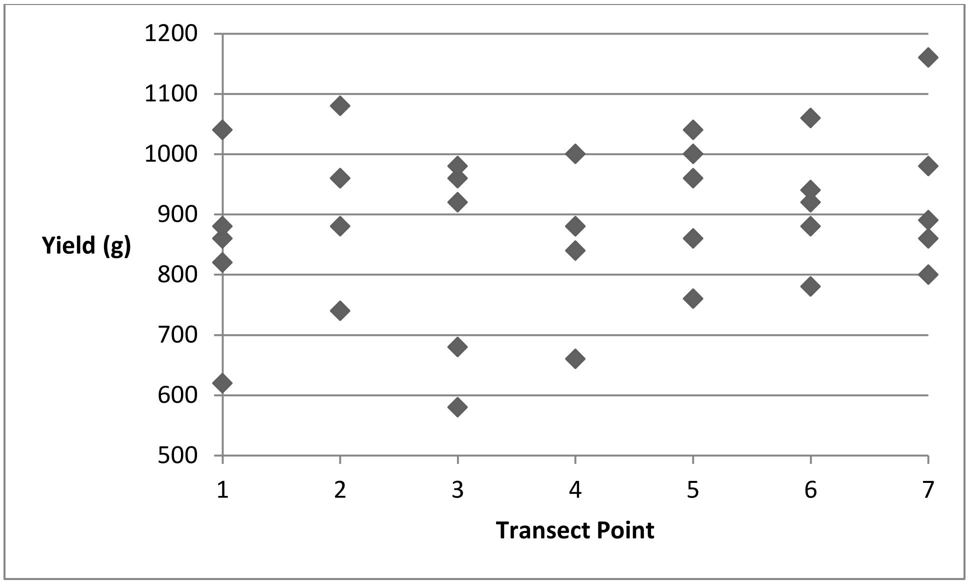

Figure 6.12. Yields (grams) for a given transect point in Field 1.

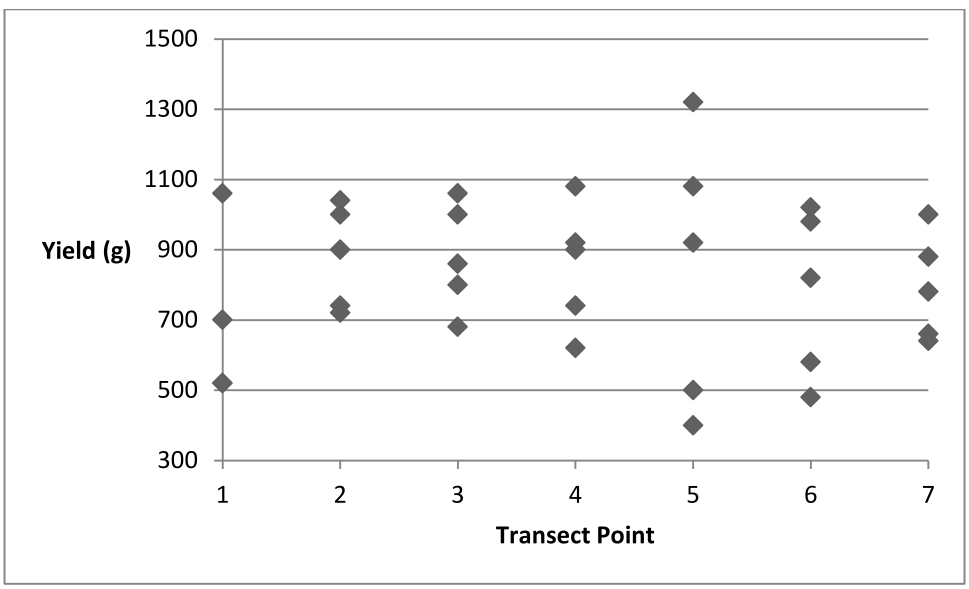

Figure 6.13. Yields (grams) for a given transect point in Field 2.

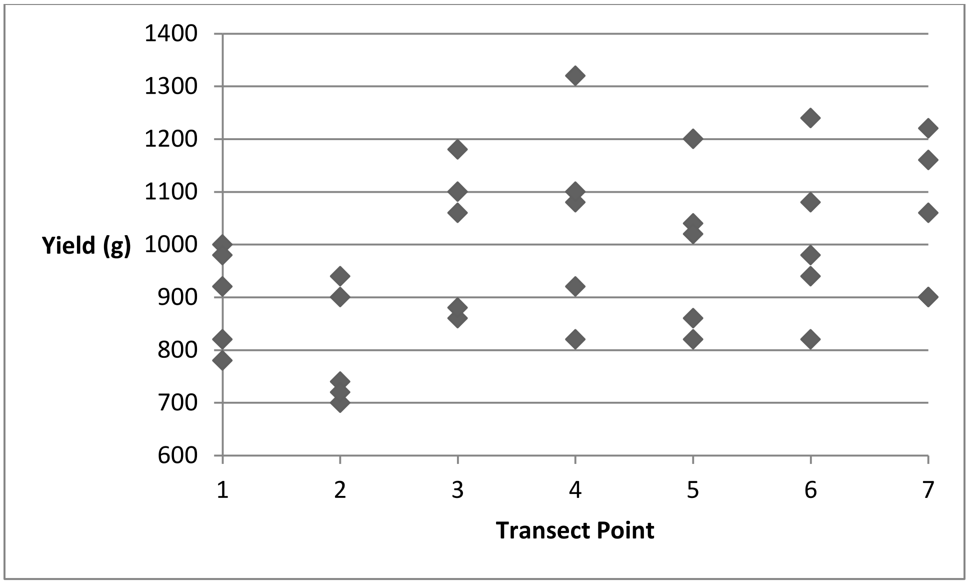

Figure 6.14. Yields (grams) for a given transect point in Field 3.

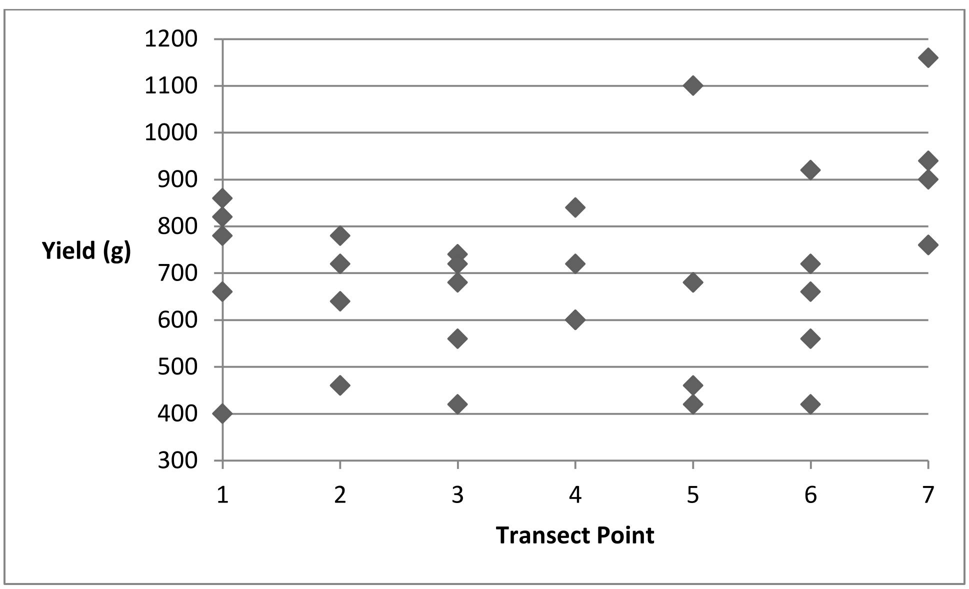

Figure 6.15. Yields (grams) for a given transect point in Field 4.

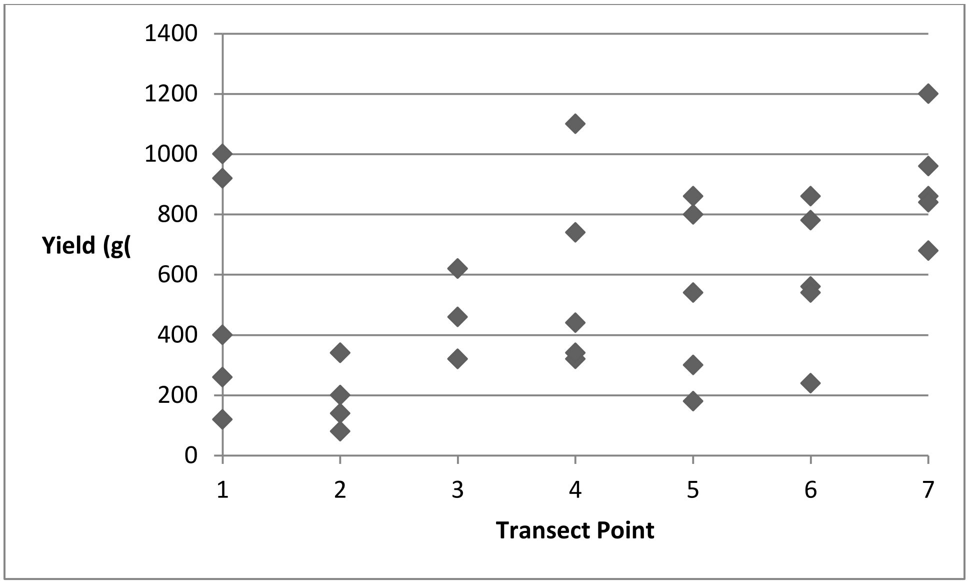

Figure 6.16. Yields (grams) for a given transect point in Field 5.

6.3.5 Slope vs. Yield

The regression confirms that yields had a negative relationship with slope (R^2=0.23, $p < 0.0001$). The strength of the regression was only marginally better without the nine points from Farmer 3 in Field 2 ($R^2 = 0.25$). The results are consistent with previous studies done on corn where fields with higher slopes experienced more variation and maximum terrain slope was found to be important, but where another factor, in this case nutrient availability, was found to be more important (Kravchenko et. al 2000; Kravchenko et. al 2005).

The yields by slope showed a clear negative trend (Table 6.5) ($p < 0.001$). The 5º and 6º slopes were not included in the analysis because they had sample sizes of 3 and 6, respectively. Slopes of 2.5º and 3º were statistically similar, but yields on slopes of 0.5º and 4º were each statistically different from yields on other slopes.

Table 6.5.

Mean yields generally decreased as slopes increased. The same letter indicates no significant difference between field yields using Tukey's test for significant difference. Slope has a significant ($p < 0.0001$; $\alpha = 0.1$) impact on yields. Degrees of freedom = 165.

Slope (º)	Mean Yield (g)
0.5	973[a]
2.5	813[b]
3	786[b]
4	567[c]

** Slopes of 5º and 6º were not included because of only possessing 3 and 6 samples, respectively.

6.3.6 Farmers vs. Yield

Fields 1 and 2 of Farmer 1 were statistically similar in yield (Table 6.6). Fields 1 and 3 were also similar, but fields 2 and 3 were not. This is difficult to explain except that Field 2 had the lowest yields when the 9 points of the Farmer 3 were included. When these points were removed, the fields were not significantly different in yield. It is likely that the yields of Fields 1-3 were not statistically different. Field 4 had yields statistically different from every other field. Field 5 did as well. Both Field 4 and Field 5 were also statistically lower in yield than the other three fields.

Table 6.6.

Mean values of yield in grams for each field. The same letter indicates no significant difference between field yields using Tukey's test for significant difference. Field has a significant (α = 0.1) impact on yields as Field 3 is different from Fields 2, 4 and 5. Field 1 is different from Fields 4 and 5. Field 2 is different from Fields 3, 4 and 5. Fields 4 and 5 are each unique. Degrees of freedom = 140. N=35.

Field	Mean Yield (g)	Mean Yield (t ha^{-1})
3	973	4.87[a]
1	889	4.44[a, b]
2	813	4.06[b]
4	691	3.46[c]
5	551	2.75[d]

6.4 Discussion

This section discusses the above analyses and why they do or do not fit with previous research on the topic of water stress and slope on irrigated upland rice fields. First, transect point, soil moisture and slope are discussed regarding why soil moisture was not significantly impacted by slope despite its reduction up- versus down-slope. Farmer practices, precipitation data and irrigation policies are presented as likely explanations. Erosion is discussed as a possible explanatory factor for why transect point and slope are more important than soil moisture when explaining yields. Second, a brief point is then made on the effect of farmers on yield differences up- and down-slope as a lead-in to a discussion on farmer management practices and the inherent complexity involved in teasing out the most important reasons for differences in yields between farmers. Third, land tenure and its effect on soil conservation and water management at the field level is discussed. This is presented as the main reason, in combination with precipitation and local irrigation policies, as to why soil moisture did not have the predicted effect on yields. Finally, a short section discusses the value of using field studies rather than research plots as a means of generating useful results locally.

6.4.1 Discussion of Transect Point, Soil Moisture, Slope and Erosion

It important to look at why soil moisture was highly correlated with transect point across testing dates for Farmer 1's fields, but was not for Farmer 2's fields although Farmer 2 was cultivating on fields of steeper slopes than was Farmer 1. One would expect from the literature that soil moisture should always be correlated with transect point. In rain-fed systems in Laos, Vietnam and the Philippines, it has been shown that series of fields increase in standing water in the lower portions of mildly to medium sloped toposequences (Boling et. al 2008; Inthavong et. al 2011). Multiple fields along a toposequence can be seen as points along a transect in the same field, but this study in Honduras did not fully corroborate with previous findings. As expected, soil moisture increased down the transects on Farmer 1's fields with slopes of 0.5°, 2.5° and 3°. This supports the research done elsewhere, but on the fields with higher slopes, little correlation was found. This does not mean that drying along the transect was not happening in Farmer 2's fields. Rather, it means that other factors on Farmer 2's fields were likely doing something that affected drying.

The Irrigation District of Flores provides large quantities of inexpensive water to the farmers. Every irrigation provides at least 1200 m^3 of water, equal to 171 mm, at a cost of \$0.004 $m^{3\ -1}$. This price has been found in other parts of the world to cover the O&M costs of well-functioning irrigation districts, but it falls far below the average values of water around the world, which include prices from \$0.05 to \$0.90 per m^3 but are more often recorded as between \$0.10 and \$0.20 per m^3 (Perry 2001). In rice production, water is seen as even more important than in other crops such as wheat, soybeans and corn because it thrives in flooded conditions, experiences water stress more easily, and transpires at a greater rate than other grains (Tanguilig et. al 1987). Farmers in Flores are more likely to overwater than underwater because the irrigation services cost them little in comparison to the value of that water. The combination of two factors, the base price of irrigation water and the fact that farmers are probably receiving much more than 1200 m^3 per irrigation because of the inability of the District to measure volume and the temptation *canaleros* face to provide extra water in exchange for bribes, support the idea that water is basically free for rice farmers in Flores, Comayagua. Rice, furthermore, is a cash crop with the best price guarantees in Honduras. This is not to say that it is the most valuable cash crop, but it is one of the most reliable.

This dynamic may be a leading explanation for why transect points did not correlate with soil moisture on Farmer 2's fields. No data was collected during the panicle initiation and flowering growth stages because he was irrigating throughout it. He was irrigating everyday non-stop for at least two weeks. When he was not actively irrigating the tested fields, he was usually irrigating other fields. This did not mean, however, that no water inputs were occurring. Rather, he often shoddily closed the canal entrances to the study fields. Water was often percolating from the field canals into the tops of the fields where the first transect points were located. The near constant water inputs supports the idea that Farmer 2's practices probably affected the data concerning soil moisture and transect point.

For both farmers, precipitation likely functioned to even the soil moisture data across transect points and fields. The differences that may have occurred due to slope were likely reduced by an abnormally rainy year. The average precipitation for the area of Flores over many years was 874 mm $year^{-1}$, but during the year of the study, Flores experienced 1479 mm of precipitation. During the five months that Farmer 1 had his rice planted, from June to October, precipitation averaged 207 mm $month^{-1}$. From July to November, the five months of cultivation for Farmer 2, precipitation averaged 198 mm $month^{-1}$. During the three key months for rice development in this study, from July through September, precipitation averaged 300 mm $month^{-1}$. For upland rainfed systems, 200 mm $month^{-1}$ of precipitation is adequate for rice production in Asia in order to achieve acceptable yields (De Datta 1981). When one considers inputs of at least 342 mm $month^{-1}$ (two irrigations) from irrigation and the addition of precipitation during the study, it is not hard to imagine that the farmers in Flores were adding up to 550 mm of water per month to their rice fields in 2010. For this reason, the results may have been different if the study had been carried out during a drier year.

A Thornthwaite analysis of the water budget for Flores, Comayagua further illustrates this point. Even in a year with normal precipitation and irrigation levels, rice would rarely if ever experience water stress (Figure 6.17). Rather, a large surplus of water would probably be wasted. For 2010, an even larger surplus was available (Figure 6.18). Farmers may have to overwater to compensate for slope, but this analysis suggests that they are

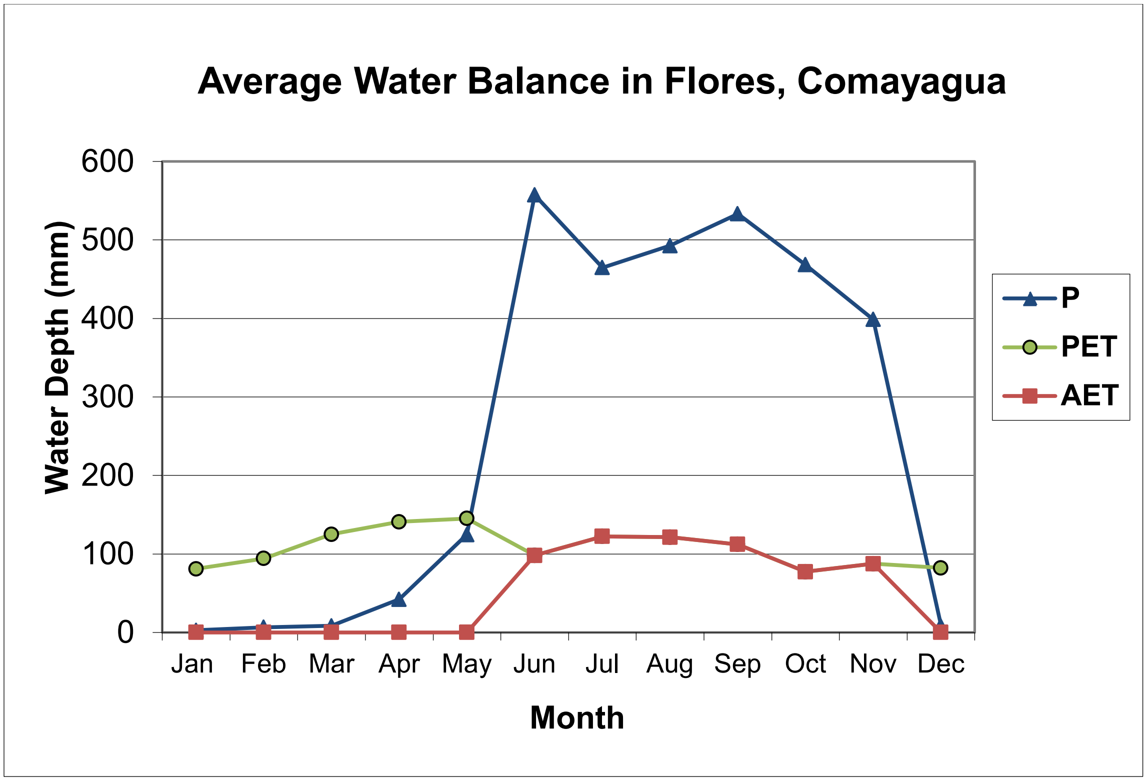

Figure 6.17. Thornthwaite analysis of water budget in Flores, Comayagua. P=Precipitation and irrigation. PET=Potential Evapotranspiration AET=Actual Evapotranspiration

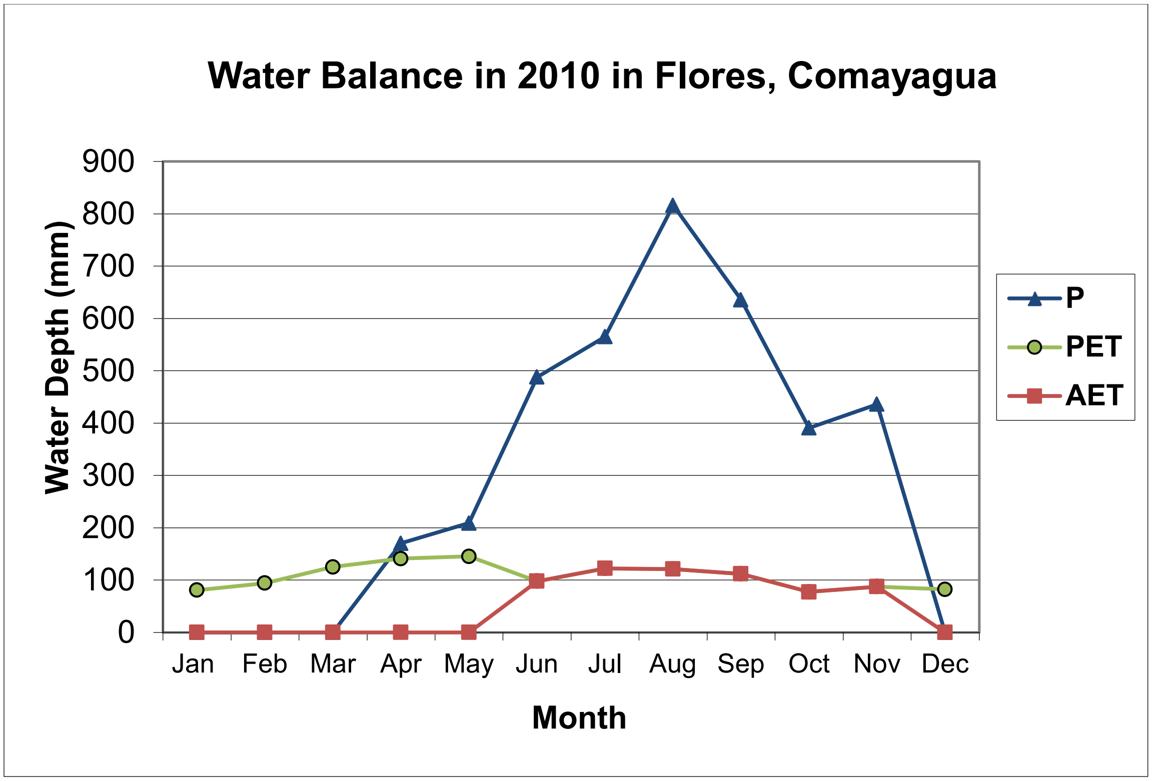

Figure 6.18. Thornthwaite analysis of water budget in Flores, Comayagua in 2010. P=Precipitation and irrigation. PET=Potential Evapotranspiration AET=Actual Evapotranspiration

overcompensating. The Thornthwaite analysis does not take slope, hardpans, runoff, or the value of flooded conditions into consideration, but it suggests that water has not been the primary constraint to optimal yields in Flores, Comayagua. Other factors, such as fertilizer application, weeds, and soil are probably contributing. It also suggests that the Irrigation District could allocate water more efficiently. If farmers could control for slope and apply water equally to the whole field, the Irrigation District could increase its coverage.

Even with higher precipitation and inexpensive and available irrigation water, one would have expected to see higher yield differences due to soil moisture differences. This is especially true because, in Flores, rice production is not flooded. Transect point positively affected soil moisture and yields but soil moisture did not greatly affect yields. The absence of standing water itself can significantly decrease yields even if water stress is not noted (Fukai et. al 1999). Losses of 0-12% are possible in fields only kept at saturation levels without flooding and losses up to 40% are possible when the soil water is allowed to drop to -100 to -300 mbar depending on frequency and severity (Bouman and Tuong 2001). One should expect to see soil moisture as a relatively strong predictor of yields in rice, but the data from Flores in 2010 shows that this is not always the case.

Transect point and slope were better predictors of yield than soil moisture. Other consequences of failing to mitigate the effects of slope may help explain why soil moisture was not correlated with slope and transect points on Farmer 2's fields, but slope and transect point were correlated with yield on Farmer 1's fields. Yearly runoff on sloped fields, where no soil conservation structures exist, can transport large quantities of soil nutrients, organic matter and fine particles down-slope (Narayana and Sastry 1985; Pimentel et al 1995). With every increase in slope even on gently sloping fields, fields experience large increases in soil loss. For example slopes of 0.29° can experience soil losses of 3.0 t ha^{-1} while slopes of 1.72° can lose 13.6 t ha^{-1} in a given year (Narayana and Sastry 1985). This then increases soil fertility in the regions down-slope in a given field at the expense of upslope regions. Fertilizer and herbicides, moreover, are not contained up-slope in this situation (Cho 2003). These factors then increase productivity down-slope if conservation structures maintain runoff from upslope on the field. Attempting to maintain high soil moisture up-slope by providing increased quantities of irrigation can compound the problem and increase yield disparities despite success in providing ample soil moisture to upslope points. This may explain part of the relative importance of transect points and slope on yield in contrast to soil moisture.

6.4.2 Discussion of Yield Differences between Farmers

Transect point and yield data show changes up- and down-slope, but farmer practices commonly smooth over the differences in yield between transect points. This is evidenced by the elimination of significant differences between yields along points when a Tukey's test was performed on Farmer 1's data alone. The clear gradient remained with a difference of 0.62 t ha^{-1} between Transect Point 7 and Transect Point 1, but it was not significant. When a Tukey's test on Farmer 2's data was again run, the general trend remained (Table 6.7). These data strengthen the case for a gradient of greater yields down the fields where the transect point 7 is significantly higher in yield than the lowest points not bordering a tertiary canal, Points 3 and 2.

Table 6.7.

Mean values of yield in grams for transect points for Farmer 2's fields. Lines above the rows indicate groups in which there is no significant difference between yields using Tukey's test for significant difference (α = 0.1.). Degrees of freedom = 69.

Transect point	7	4	6	1	5	3	2
Mean Yield (grams)	906	630	626	622	602	546	416

6.4.3 Discussion of Management Styles

Management strategies and slopes likely had the greatest impact on differences in yield because the three fields of Farmer 1 had the highest and similar yields. They were also the fields with the lowest slopes except for three points on Field 1 that had 5° slopes. The two fields of Farmer 2 likely had different yields because of soil quality and slope differences.

Results may have been partially caused by the differences between farm management styles, higher nutrient levels and the difficulty of distinguishing between slope readings for fields with similar slopes. In comparison to Farmer 1's fields, Farmer 2's fields had lower levels of P, K and Na, which can substitute for K in some minor processes such as maintaining cell turgor (Yoshida 1981). Rice has been demonstrated to have a high demand for potassium (Greenland 1997). Farmer 1 said in the survey that he applied 259 kg of 12-24-12 and 65 kg of KCL per hectare to his fields. Farmer 2 did not apply any K to his fields and instead applied an unknown quantity of 18-46-0 fertilizer. Based on observations and informal conversations during the course of the study, Farmer 2 preferred to use his fields in the offseason for pasture. The removal of rice straw has been documented to reduce storage of K by upwards of 160 kg ha^{-1} $year^{-1}$ on irrigated rice fields with no sediment inputs

(Greenland 1997). In contrast, Farmer 1 preferred to allow a week or two of grazing and leave the three tested fields in fallow for a majority of the year and thus retained a majority of the rice straw. The combination of these differences may help explain part of the difference in yields between the farmers.

One should be careful to remember that many factors are interacting and may influence the yields on individual fields. This makes it difficult to say that one factor is the most important. Farmer 1 had an advantage because his fields were of lower slopes and had better soil. Slope and soil alone may not explain the differences between Farmer 1 and Farmer 2. Farmer 2 had the advantage of more sunny days and less rain during the reproductive and ripening stages, the stages when the plants are most able to utilize the sunlight and the plants should be protected from drought stress (Yoshida and Parao 1976; Yoshida 1981; Srivastava et. al 2009). Farmer 2 irrigated constantly for two weeks during these stages when the plants most require both sunlight and also water (Bouman et. al 2007). Farmer 2 should have expected to see higher yields, furthermore, because irrigated dry season yields are usually higher than irrigated rainy season yields as a result of increased solar radiation (De Datta 1981; Khush 1997). It was possible that this was off-set by the difficulty of properly irrigating the 4º and 6º slopes of Field 5 without washing away nutrients and organic matter.

The differences in the time of planting, the skill and difficulty involved in irrigating variously sloped fields, the timing and amount of irrigation, and the amount and application of fertilizers, insecticides and herbicides may explain a part of the variation in the data analyses. These differences, however, do not take away from the fact that farmers in this area are losing significant amounts of rice yields by not mitigating the effects of slope.

6.4.4 Discussion of Rationality and Land Tenure

Farmers may, however, be acting rationally. The surveys with the farmers indicated that contract issues and land tenure may be an important reason why they are not using soil conservation and slope-mitigation techniques. It has been well-established that land insecurity has negative impacts on the use of soil conservation structures (Beets 1990; Alemu 1999; Soule et. al 2000). Renting land has sometimes been considered in a different light than insecure land rights, even to the point of encouraging early adoption of soil conservation technologies, but this has been contradicted in Honduras by hillside farmers reluctant to invest in organic matter technologies when they do not have guaranteed continued access to the fields (Polson and Spencer 1991; Arellanes 1994). Likewise in the case of the rice farmers of Flores, it was not in the best interest of the farmers to over-improve rented land because of the risk that the owner of the land would want the land back if it became too profitable. At the time of the study, contracts in general only lasted from six months to a year. If farmers were to improve the land by construction of soil bunds or other soil conservation features, the possibility existed that the owner would demand the land back or not rent the land the following year and the farmers would lose their investment and access to the fields. This was, at least, their perception.

If this was the case, it was in the best interest of the farmers to ignore investments in the land and instead concentrate on water and fertilizer inputs. Water was easy to control because it cost little. Farmers were putting more than enough water on the field for upland systems of rice production. When discussing farm management, farmers stated that they were investing in fertilizers and other chemical inputs. The other factor to consider is that, especially for the two farmers studied in this paper, scale was important. Instead of farming intensively, the goal was to farm extensively; mechanization made this both possible and also preferable in their eyes. Farmer 1 owned five tractors and two combines. Other farmers paid him to prepare and harvest their fields. All land preparation and harvesting of rice in the Irrigation District was done with large machinery. At 55 ha for Farmer 1 and 75 ha for Farmer 2, both farmers farmed areas much larger than the average in the Irrigation District. Rather than focus on making the most money out of five hectares, they both focused on farming relatively well on large areas. This was no doubt influenced by irrigation availability, land tenure, and the availability of machinery for land preparation and harvesting. These factors likely outweighed the importance of soil moisture and slope on the rice fields of Flores during 2010.

6.4.5 Value of Field Studies vs. Research Plots

This study used field plots in order to test how soil moisture interacted with slope and yield in the farm system of rice farmers in the Irrigation District of Flores. One could say that this approach was vindicated by the results. If research plots, instead of field trials, had been used, the results likely would have been different and, more importantly, useless to local farmers. The reason for this is simple. On research plots, the study would likely have applied a steady amount of water per month, 200 mm for example, well below the inputs that other farmers were putting on their fields. The results would have likely mirrored theory and prescriptions for other farmers would have included the need to apply more water to make up for losses caused by slope. It would have also suggested that farmers install conservation structures to improve water use efficiency. This advice would have disregarded the importance of land tenure on improved management techniques and land access, thereby giving useless information to farmers in a region where they already were applying large quantities of water because of social and infrastructural factors.

6.5 Summary

Soil moisture was positively affected by transect point down the slope, but slope played little or no demonstrated role in the relative moisture levels. Position along transect toposequences nonetheless significantly affected yields; one could expect to find higher yields farther down the slope. Furthermore, one could expect to find lower yields on fields with greater slopes. The results show that a variety of factors worked to complicate the system and weaken the effect of soil moisture and slope on yields. These factors included, but were not limited to, inherent field soil characteristics, fertilizer regime differences, access to extra irrigation water, precipitation levels and timing, and land tenure.

CHAPTER SEVEN - CONCLUSIONS

The complicating factors do not, however, weaken the argument that farmers are losing significant amounts of rice yields by not making efforts to mitigate the effect of slope on soil moisture and/or nutrient leaching. The difference in yields up- and down-slope matters to the farmers even if they do not realize it. From the surveys with the two farmers involved in the study, it is clear that there is a lack of understanding regarding the amount of yield losses they are incurring by failing to mitigate for slope. When asked what he perceived were his losses up-slope versus down-slope, Farmer 1 responded by saying that he estimated something around 1 t ha^{-1}, but this was an estimate based on the ranges of yields he knew from field to field; it was not an estimate of on-field losses up-slope versus down-slope. His answer suggested that this was an uncommon concept for him. Regarding Farmer 2, he casually stated that the difference between Transect Point 7 and Transect Point 1 was probably about 0.50 t ha^{-1}. This was a large underestimate as the data from this study showed that he was losing 1.42 t ha^{-1}. Clearly, there exists some confusion about yield losses on individual fields as a result of slope.

If the farmers could mitigate the effect of slope, the data suggests they could increase their profits substantially. It costs, according to the farmers in this study, about 22,000 lempiras ($1,165.25) to produce 3.9 t ha^{-1} of rice. If the farmers could manage their fields uniformly to attain the yields of the higher performing lower portions of the transects, they could make more money. The average yield for all of the points was 3.92 t ha^{-1}. Average yields for the rice variety, DICTA 6-60, across seven studies in Honduras was 4.74 (range from 3.18 t ha^{-1} to 8.5 t ha^{-1}). It is conceivable that the farmers of the Irrigation District of Flores could raise production to 4.59 t ha^{-1}, the Transect Point 7 level and an increase of 0.67 t ha^{-1}, by uniformly managing their fields. In 2010, the average farmer in Flores had about 4.53 ha in rice production. If a normal farmer has a net profit of $281 ha^{-1} ($1272 per 4.53 ha), a farmer mitigating slope could have a net profit of $537 ha^{-1}, a difference of $256 ha^{-1}. That suggests that the normal farmer is losing upwards of $1159 by not mitigating for the effects of slope on yields. Whether the farmers of Flores know it or not, they are incurring large losses by failing to account for the effects of slope and toposequential position on the farm field.

This study confirmed that slope was affecting yields in the Irrigation District of Flores in Comayagua, Honduras. The value of field studies was also verified in that the data suggested issues such as tenancy and poor on-field water and fertilizer management that logically followed from the farming system may be better explanatory variables for yield than simple water scarcity. The field study also usefully suggested that the farmers were, contrary to the original hypothesis, over-watering the fields because of the inexpensive cost of water and the assumed value of dumping large quantities of water onto the fields. That a yield gradient was nonetheless apparent suggested that this strategy was causing or not accounting for other factors such as erosion and nutrient leaching. The uncontrolled field study method, however, does not allow for all variables to be measured. This study could not confirm the exact composition of the factors influencing yield losses up- versus down-slope.

It would be beneficial for future studies to look at larger groups of fields with disparate levels of slope in the Irrigation District of Flores to determine whether slope, soil moisture, erosion, fertilizer regimes or other factors are causing the yield losses up-slope. Given the variable economic climate of Honduras and the year-to-year changes in the negotiated price of rice, it would be beneficial to develop a model for determining the appropriate goals for farmers in a given year. It would be enlightening to see what it would take for the region to become more intensive in production rather than extensive, as is now the case. Furthermore, it would be useful to determine the optimal pricing of irrigation water in order to maximize regional yields and minimize soil loss through erosion.

Largely without outside guidance, the people of Flores have built a functioning and diversified agricultural system. They are not reliant on rice even though it is currently the most popular cash crop. Production has been known to drop dramatically in the past in Honduras because of economic and trade factors; this could happen again. During those times, *Floreños* adapted their system to meet the changing demands. It is possible that rice farming does not continue for long in Flores, but the resilience of its people gives them the ability to respond to change and thrive despite an unclear future.

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APPENDIX A – CLIMATE DATA

The following data was taken from Almedarez's 1988 Volume 4 report, "Zonal Agroclimatic Asssessment" for the south-central-western region of Honduras as produced by the Agro-meteorological Section of the Department of Hydraulic and Climatic Service of the Directorate of Hydraulic Resources of the Department of Natural Resources (SERNA).

Table A.1.

Decadal precipitation in mm in Flores, La Villa de San Antonio, Comayagua, Honduras between 1972 and 1986.

Decade	J	F	M	A	M	J	J	A	S	O	N	D
1	1.0	1.0	1.2	4.8	18.1	71.0	32.2	27.5	61.0	36.4	12.6	4.9
2	0.6	4.9	3.7	15.0	15.0	72.2	22.6	33.7	113.0	26.2	7.7	2.0
3	0.9	0.3	3.9	21.6	60.0	40.0	40.6	59.6	65.5	31.8	5.9	1.4

Table A.2.

Monthly precipitation in mm in Flores, La Villa de San Antonio, Comayagua, Honduras between 1972 and 1986.

J	F	M	A	M	J	J	A	S	O	N	D
2.7	6.5	8.4	42.3	124.5	185.4	92.7	120.6	161.2	95.6	26.8	8.4

Table A.3.

Distribution of annual precipitation based on season in Flores

Avg. Annual Precip. (mm)	Avg. Precip. (May – Oct) (mm) and % Total	Avg. Precip. (Nov – Apr) (mm) and % Total
876	781 (89%)	95 (11%)

Table A.4.

Amounts of expected rain in Flores according to different probabilities

Station	Probability	J	F	M	A	M	J	J	A	S	O	N	D
Flores	25	4.7	8.4	11.1	57.1	168.0	209.2	122.2	144.6	220.6	126.2	40.5	14.5
	50	2.5	1.1	5.1	60.6	110.2	175.6	79.1	113.7	152.3	88.3	22.9	8.1
	75	0.6	0.2	0.0	15.0	92.4	146.8	65.4	100.1	92.8	51.5	7.5	1.4

Table A.5.

Average Monthly Temperature (Celcius)

Station	J	F	M	A	M	J	J	A	S	O	N	D
Flores	22.5	23.6	25.8	26.6	26.7	23.3	25.2	25.2	24.7	22	23.1	22.7

Table A.6.

Average Monthly Minimum Temperature (Celicius)

Station	J	F	M	A	M	J	J	A	S	O	N	D
Flores	16	16.4	17.4	18.7	20.3	19.7	18.9	19.2	19.3	19	17.6	16.4

Table A.7.

Average Monthly Maximum Temperature (Celcius)

Station	J	F	M	A	M	J	J	A	S	O	N	D
Flores	28.3	29.6	32.3	32.5	32.2	30.2	30.1	30.4	29.9	28.7	27.8	28

Table A.8.

Record Lows for Month (Celcius)

Station	J	F	M	A	M	J	J	A	S	O	N	D
Flores	8.2	8.2	11.4	14.2	14.7	14.1	14.4	14.2	12.8	11.1	8.7	11.9

Table A.9.

Record Highs for Month (Celcius)

Station	J	F	M	A	M	J	J	A	S	O	N	D
Flores	32.7	34.0	35.7	35.6	35.2	32.8	32.0	32.5	32.5	31.3	31.4	31.5

Table A.10.

Soil Temperature (Celcius) at different depths

Depth (cm)	J	F	M	A	M	J	J	A	S	O	N	D
5	23.5	25.8	28.4	28.1	28	26.2	25.8	25.9	26.3	25.6	23.8	23.5
30	24.1	25.5	27.6	27.7	27.1	26.3	26.1	26.2	26.6	25.7	23.7	23.4
50	24.1	25.1	26.7	27.5	27.7	27.1	26.8	27.1	27.1	26.4	25.1	24.8
100	25.2	25.4	26.3	26.8	27	27.2	27.1	27.1	27.1	26.9	27.1	25.7

Table A.11.

Average Relative Monthly Humidity (%) in Flores

Station	J	F	M	A	M	J	J	A	S	O	N	D
Flores	69	65	59	62	68	76	72	73	70	78	76	72

Table A.12.

Average Monthly Evaporation (mm) in Flores

Station	J	F	M	A	M	J	J	A	S	O	N	D
Flores	161.6	181.2	239.3	217.3	182.4	145.8	154.7	154.3	130.1	131.7	122.7	139.4

Table A.13.

Average Solar Radiation (cal./cm^2/day) in Flores

Station	J	F	M	A	M	J	J	A	S	O	N	D
Flores	288.2	394.5	463.7	372.1	375.6	310.0	329.8	363.1	321.6	322.4	294.5	338.7

Table A.14.

Monthly Potential Evapotranspiration (mm) in Flores

Station	J	F	M	A	M	J	J	A	S	O	N	D
Flores	129	136	181	186	179	153	172	170	162	136	123	133

Table A.15.

Potential Evapotranspiration (mm) in Flores by 10-day Decades

Decade	J	F	M	A	M	J	J	A	S	O	N	D
1	42	47	55	61	59	53	54	55	54	48	42	43
2	41	49	58	62	53	51	55	55	54	44	41	43
3	41	42	65	61	62	52	61	55	51	47	42	47

APPENDIX B

SAS code used in the data analyses

Tukey Studentized Range (HSD)

```
proc glm; class  TP1 FV1  ;
model GRAM =  TP1 FV1    TP1*FV1 ;
means  TP1 FV1 /tukey alpha=.1 ;

*proc end;
```

Basic GLM

```
PROC GLM ;

MODEL   GRAM  =
SMV3  SMR3

SMM3
;
```

Paired T-Test

```
=proc ttest; paired  SMR3*SMM3  ;


proc end;
```

Correlation

```
PROC CORR ;

VAR      SMV1       SMV2   SMV3

         SMR1       SMR2      SMM1          SMM2        SMM3
SLOPE         GRAM
TP1    ;

 *WITH    GRAM
FDUM1     FDUM2     ;

RUN;
```

APPENDIX C

Oral Consent Statement

ENGLISH

“In addition to my duties working in agriculture and agricultural extension, I am writing a report as part of my education at my university in the United States. I would like to talk to you from time to time about some of your experiences with rice farming. I may use what you tell me in my written report to my professors at my university. I will have some particular things I would like to talk about but my may ask me questions and talk about things you think I should know about, even if I don’t ask. You are not required to talk to me or answer my questions. Even if you decide now to talk to me about rice farming you may later ask me to stop asking you about it. When you ask me to stop, I will stop asking you about rice farming. You decide if you want to talk to me about rice farming. Nothing bad will happen to you or to me if you decide not to answer my questions about rice farming.”

SPANISH

“En adición a mis funciones trabajando como técnico agrícola y forestal, estoy escribiendo un reporte como parte de mi educación en mi universidad en los EE.UU. Me gustaría hablar con usted a vez en cuando sobre algunas de sus experiencias con la cultivación de arroz. Quizás utilizaré lo que me diga en mi reporte escrito a mis profesores en mi universidad. Tendré algunas cosas específicas de que querré hablar pero usted podrá hacerme preguntas y hablar de lo que quiera aun que no yo no le haga la pregunta. No es requerido que me hable o conteste. Aun si decide hablar ahora sobre el tema de la cultivación de arroz, puede pedir me después no hacer más preguntas. Cuándo me dice que pare, pararé de hacerle preguntas sobre el arroz. Usted decide, no yo, si quiere hablar conmigo sobre la cultivación de arroz. Nada malo pasará a usted o a mi si decida no dar repuestas a mis preguntas sobre la cultivación de arroz."

APPENDIX D

Permissions

Received via email on 8 November 2011.

Mr. Earnshaw,

Congratulations on getting your thesis ready for submission! Thanks for thinking of me, but as you already know, it was my pleasure to work with you that weekend, and to get to work in a Central American Rice field. Therefore, you can include me in your acknowledgements only if you want to. You are of course authorized to use any fotos of me you like.

Again Congrats, amigo!

Parker Filer

Figure 2.1

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